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THE ELECTRICAL PROPERTIES OF THE VAPORS FROM THE CARBON ARC.

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In experiments upon the discharge of negative electricity by light the electric arc has usually been found to be the most satisfactory source of ultra-violet rays. It was early recognized, however, that serious errors might arise from the employment of the arc. Inductive effects were readily prevented by metal screens; but there were reasons for believing that electrified particles, thrown off from the hot carbon terminals, and proceeding to considerable distances from the arc, were a still more serious source of trouble. To prevent disturbances from this cause a screen of quartz or gypsum has usually been interposed between the arc and the body whose discharge is to be tested. Experiments made by Hallwachs[1] in 1890 indicate that even the double protection afforded by a quartz window covered by wire gauze may in some cases be insufficient. When an arc was used whose positive carbon contained a core of tin, it was found that positively charged particles were given off so freely that evidences of electrification of the air were found in all parts of the room. The experiments of Hallwachs indicated the presence of positive particles only. In view of the high temperature and rapid disintegration of the positive carbon this result would naturally be anticipated.

When actino-electric experiments are carried on in the immedi-

[1] Wiedemann's Annalen, Vol. 40, p. 332, 1890.

ate neighborhood of the open arc the results are apt to be especially misleading. The attention of one of the writers was called to this fact during the course of a series of lectures upon the general subject of the discharge of negative electricity by light. As an illustration of the fundamental phenomenon various negatively electrified bodies were brought near the arc, held there for an instant, and then tested by an electroscope. They were always found to be completely discharged. But if the charged body was placed within 20 or 30 cm. of the arc the discharge was found to be equally rapid and complete when a *positive* charge was used. At greater distances no indication could be found of any effect upon positive electricity.

In these experiments the conditions were such as to suggest that the dissipation of a positive charge was due to the action of the hot gases from the arc. In fact it was found that the gases still possessed this power of discharging an electrified body after they had been drawn through a metal tube to a considerable distance from the arc. Positive and negative bodies were discharged with apparently equal rapidity. If this action is to be explained by the presence of electrified particles, we must therefore assume that positive and negative particles are present in almost equal numbers.[1] This fact alone makes it seem improbable that electrified particles, in the ordinary sense, can be the real cause of the phenomenon; for the great difference in the temperature of the two carbons makes it extremely unlikely that positive and negative carbon particles would be given off in equal amount. It appears more plausible to assume that the vapors from the arc are in a condition similar to that of a gas that has been acted upon by X-rays, or to the hot gases from a flame. It is supposed in these cases that a condition is developed in the gas somewhat similar to that in an electrolyte, *i. e.*, ions are formed, some carrying positive charges and others negative charges. This condition is only temporary; in the case of X-rays, for example, the gas loses this ionized state, in about one-tenth of a second. A

[1] It will be observed that this conclusion is directly opposed to that reached by Hallwachs, who found evidence of positive particles only. In the experiments of Hallwachs the positive carbon contained a core of tin. In our own experiments homogeneous carbons were used.

charged body placed in the ionized gas would attract one kind of ions and repel the other. Upon coming into contact with the charged body the ions are supposed to give up their charges and to cease to exist as ions. The action of the carbon arc always results in a certain amount of combustion, as well as in other chemical changes; this chemical action alone might account for the ionization of the resulting vapors. It seems probable, however, that the intense heat and the violent electrical forces to which the vapors are subjected are still more important factors in producing the ionized condition.

The experiments described below were undertaken in order to study more in detail the conducting property possessed by the arc vapors. In planning the experiments the known properties of gases ionized by the action of X-rays were kept in mind, for it has been our desire to bring out both the resemblances and the differences between the two classes of phenomena.

Apparatus and Experiments.

The general features of the apparatus are shown in Fig. 1. Vapors from the arc *A* were carried through the tubes *m* and *L* and past the body *B* by suction applied at *P*. *B*, the body that was

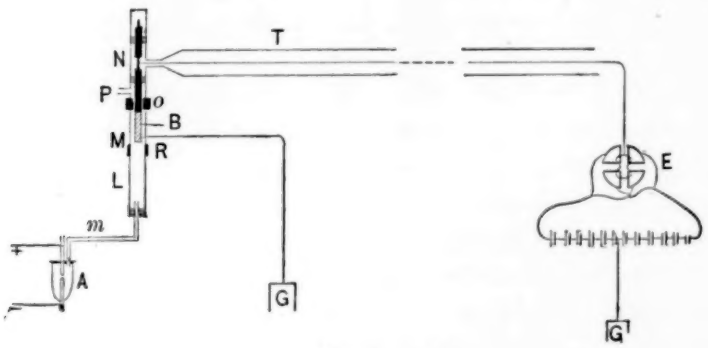

Fig. 1.

to be discharged by the gases, was a brass cylinder *10.0* cm. long and *1.2* cm. in diameter. The tube *M*, also of brass, was *16.7* cm. long and *2.5* cm. in diameter, and was kept grounded. In some of the experiments the tube *L* was of brass, in others it was glass tubing held

in place by a short piece of large rubber tubing, R. m will be described later. The potential of B was measured by the electrometer E, to the needle of which B was connected. The brass tube N and the tin sheath T surrounding the wire connecting B and E acted as a screen against external static disturbances.

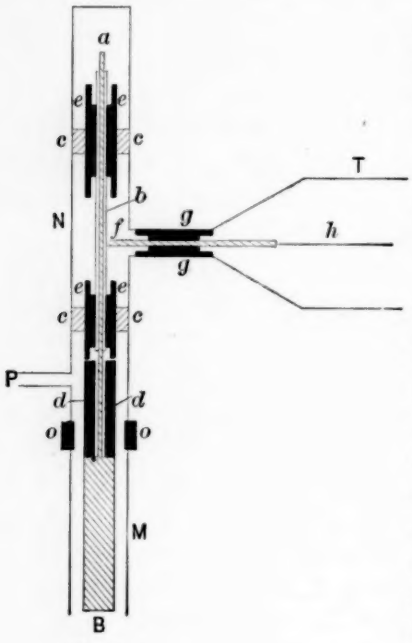

Fig. 2.

As nearly all the experimental work was performed in damp weather, and as moisture from the vapors was sometimes condensed in the neighborhood of B and on its suspension, some trouble was experienced in keeping B and its connections well insulated. In Fig. 2 is shown the insulation as finally used. The brass rod a, which was screwed into the upper end of B, slipped rather tightly through a small brass tube b. The latter was fitted into the ebonite tubes ee, which in turn were held tightly by the cork disks cc. The ebonite tubes ee were turned out at the ends in the manner shown in order to increase the surface over which leakage would occur. To still further improve its insulating power the surface of the ebonite was polished. The ebonite tube d protected a from the discharging action of the vapors. At f a brass rod was connected to b, and held in place by the ebonite tube g. To this rod was connected the copper wire leading to the needle of the electrometer.

The insulation thus secured reduced the leakage from B to the outer sheaths to a small rate even when there was a potential difference of 300 volts. This leakage, of course, decreased as the potential difference was made less, and for small differences was entirely negligible. By slightly modifying the connections it was possible to work under such conditions that the leakage was always

that corresponding to a small potential, so that correction for leakage was unnecessary. This was accomplished by insulating the grounded tube M from the upper tube N by an ebonite ring, o, and making permanent metallic connection between N and T. The latter tubes could then be raised to the same potential as B and its connecting wires, thus removing all tendency for leakage to occur.

In making observations N, T, and B were first charged to the same potential by a water battery. N and T being left connected to the battery, B and the electrometer needle were insulated from it. As the potential of B fell, due to the discharging action of the gases, readings of the electromotor were taken every ten seconds for forty or fifty seconds. The discharge produced by the gases was never so rapid as to cause any great change in the potential of B during this short interval. The potential difference between B and the sheaths N and T was therefore never large enough to cause a leakage that could not safely be neglected.

Suction was furnished by two water aspirators. As the water pressure was quite constant these gave a fairly steady suction.

The time required for the vapors to reach the body B from the arc was obtained roughly by timing the interval between the time that the water was turned on at the aspirators and the instant the needle of the electrometer began to move.

For measuring the potential a Villari electrometer was used. As shown in Fig. 1, one pair of quadrants was connected to one terminal of a battery and the other pair to the other terminal, the middle of the battery being grounded. The sheath of the electrometer was also grounded. The needle was connected to the body B as already described. Readings were taken with telescope and scale in the usual manner. To correct for slight variations in the constant of the instrument the deflection for a known potential was taken each day, and as the form of the calibration curve had been accurately determined, readings could readily be reduced to volts.

The combined capacity of the body B, the electrometer needle, and their connections was measured and found to be .00025 microfarads. In measuring the capacity the outer tubes M, N, and T were grounded; B, after being raised to a known potential, was insulated and placed in multiple with a condenser of known ca-

pacity, after which its potential was determined by the deflection of the needle. From these data the capacity of the system is readily obtained.

The arc was regulated by hand. At first an attempt was made to maintain an arc of a constant length. But more consistent results were obtained when the potential difference between the two carbons was kept constant, usually 50 volts, and a constant current maintained. This was done by constantly adjusting the carbons and varying a resistance in series with the arc, so as to keep the needles of the voltmeter and ammeter quite steady.

At first a horizontal arc was used with the tube L projecting vertically downwards within a few centimeters of the arc. The tube L had a double bend in it to prevent ultra-violet light from reaching B. To prevent trouble due to irregular air drafts the lower part of L and the arc was at first surrounded by an upright asbestos cone with the lower part open. This was not wholly satisfactory, and several other forms of enclosure were tried before entirely consistent results were obtained. Finally the arc was placed in a glass globe such as is used in the Marks enclosed arc. The carbons were mounted in the usual vertical position. Through the top iron plate a hole was drilled to admit the tube m (see Fig. 1). Asbestos packing was used around this plate to make it more nearly air-tight. A hole was drilled through the holder of the lower carbon, and a brass tube inserted through the base of the lamp so that air or any other gas could be admitted at the base of the lower carbon. All numerical results given here were obtained with this form of the arc.

Relation Between Potential and Discharge Current.

Experiments with the conductivity of gases from flames, and of gases which have been acted upon by X-rays and Becquerel rays, show that the conduction in these cases is not in accordance with Ohm's law. The current through a gas which has been ionized by either of these methods is proportional to the potential difference only when the latter is quite small. For high potentials the current approaches a maximum and remains nearly constant for further increase of potential; in other words it reaches "saturation."

Our first experiments were made to determine whether a similar phenomenon could be observed in the case of the arc vapors. It seemed advisable to measure the discharge rate for both positive and negative charges, since the unsymmetrical conditions in the arc led us to look upon an inequality in the two rates as not improbable.

In the observations recorded in Table I the brass tube L was shortened and the arc raised so that the quarter-inch iron tubing m was within three or four centimeters of B. m was held in place in L by a tightly fitting cork. The total length of the tube m was 24 cm. Results tabulated below give the discharging action of the gases from the arc for different potentials, and are recorded in the order in which the observations were made. The observed rate of change of potential is reduced to current in ampères per square centimeter of the body B. These results are also shown graphically in Fig. 3.

TABLE I.

Vapors drawn through an iron tube 0.6 cm. in diameter and 24 cm. long. The time required for vapors to pass from the arc to the body B was 2.5 sec.

Potential (volts).	Discharge current. (Amperes per square cm.)	Potential (volts).	Discharge current. (amperes per square cm.)
−131.	$112. \times 10^{-13}$	+ 73.9	81.6×10^{-13}
− 89.5	86.2	+ 52.6	59.8
+112.	113.	+ 31.5	36.2
+ 20.8	29.6	− 75.1	66.0
+ 10.7	15.9	− 34.8	30.2
− 19.4	36.5	−230.	147.
−212.	147.	+241.	157.
+166.	141.	+176.	138.
+211.	157.		

Inspection of the curve shows a decided tendency toward saturation, and this same tendency in greater or less degree was observed in all of the numerous curves taken later. Complete saturation was not reached, however, in any case, even with a potential slightly greater than 300 volts.

Discharge of Positive and Negative Electricity.

It will be noticed that in the case of the curve shown in Fig. 3 the discharge rate is slightly greater for a positive charge. Re-

peated trials afterwards showed, however, that the rate of discharge of positive electricity was the same as that of negative, so that the inequality shown in Fig. 3 is doubtless due to accidental causes.[1]

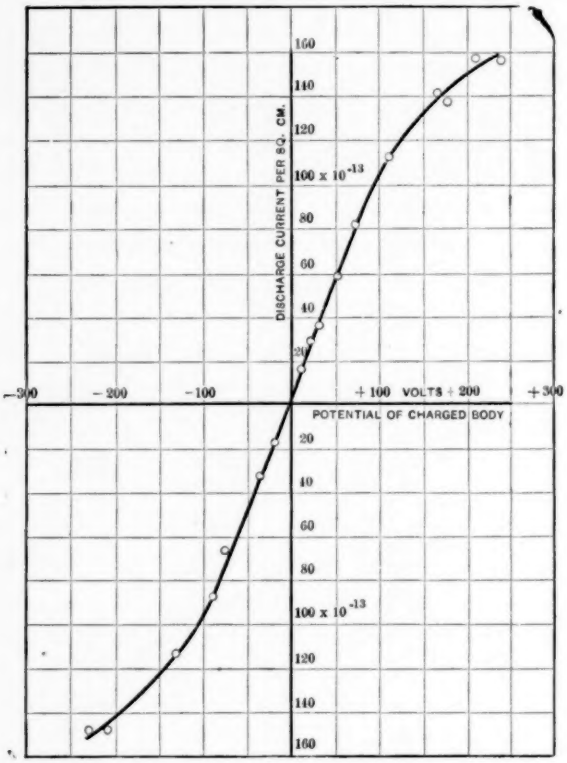

Fig. 3.

By shifting the position of a ground on the circuit the potential of the whole arc could be changed from positive to negative; but this was without effect on the equality of the two rates. Owing to the unequal temperature of the carbons, and the fact that the arc itself was not at zero potential, we had expected to find the rates unequal, and therefore suspected that the properties of the vapors were modified by the metal tubing through which they had passed. If there were

[1] The inequality might have resulted from placing the lower end of *m* too close to the arc. The effect of the position of *m* upon the discharging power of the vapors is discussed later.

an excess of positive or negative ions in the vapors drawn away from the arc, an equal and opposite charge would be induced on the inside surface of the iron tubing. The ions which would be in excess would then be drawn to the walls of the tube and neutral-

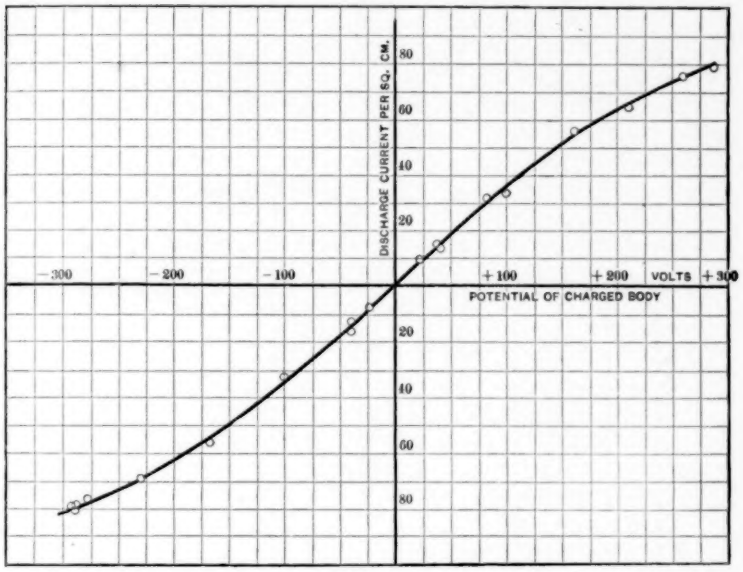

Fig. 4.

TABLE II.

Vapor drawn first through a glass tube 0.8 mm. in diameter and 23 cm. long, and then through a second glass tube 2.5 cm. diameter and 20 cm. long. The time required to pass from arc to B was 3.5 sec.

Potential (volts).	Discharge current. (Amperes per square cm.)	Potential (volts).	Discharge current (Amperes per square cm)
+100.	33.3×10^{-13}	− 24.0	7.8×10^{-13}
− 99.	32.9	+ 20.9	9.3
−293.	78.7	+260.	75.6
+289.	78.0	−287.	80.8
+ 40.4	12.9	−167.	56.4
− 41.2	12.9	+162.	55.8
−230.	69.9	+ 39.0	14.6
+209.	64.1	− 40.0	16.3
+ 83.2	30.9	−289.	78.6
−278	76.7		

ized. For this reason glass tubing was substituted for the iron tubing. The brass tubing L was replaced by one of glass 20 cm. long and 2.5 cm. in diameter. The glass tube m was 8 mm. in diameter and the total length 23 cm. It was found, as shown in the following table and in Fig. 4, that the rates of discharge of positive and negative electricity were still equal.

Arc Vapors Compared with Flame Vapors.

The curves shown in Figs. 3 and 4 are strikingly similar in form to those obtained by other observers in experiments with flame

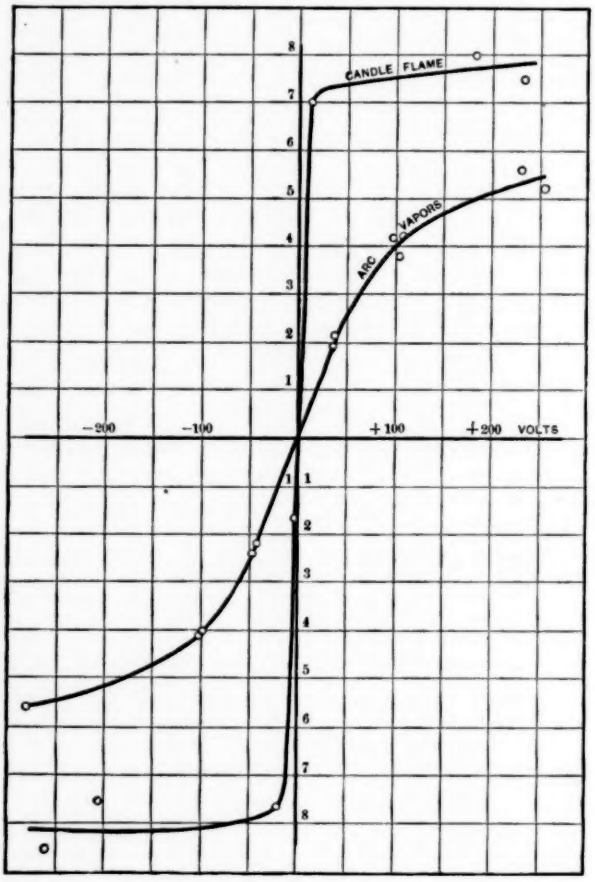

Fig. 5.

vapors, provided that the latter are plotted to suitable scale.[1] To some extent, however, this resemblance is misleading. If the vapors from a candle flame or Bunsen burner are tested under the same conditions as those to which the arc vapors were subjected, the resulting curves indicate that the electrical properties are very different in the two cases. The two curves shown in Fig. 5 illustrate this fact quite strikingly. In these curves, as in Figures 3 and 4, the ordinates give the values of the discharge rate; but these values have been plotted to an arbitrary scale. Both curves were taken with the same apparatus and under practically the same conditions. It will be noticed also that the maximum discharging power of the arc vapors was nearly the same as that of the candle flame. But in the case of the gases from the candle saturation was reached at a potential of about 20 volts, while with the arc vapors saturation was not complete even at 250 volts. If the arc vapors are compared with gases that have been ionized by the action of X-rays the curves are found to differ in much the same way.

Duration of Ionized Condition.

The arc vapors retain their discharging power much longer than do gases that have been acted on by X-rays. In the experiments giving the results stated in Table I. the time required for the vapors to pass from the arc to the body B was 2.5 seconds; in other experiments the discharging power was readily detected ten seconds after the vapors had left the arc. It will be remembered that the conducting power imparted to gases by the X-rays persists for only about one-tenth of a second.

As the distance between the arc and the body B is increased, the rapidity of the discharge produced by the vapors becomes less. We have not yet investigated the law of this decrease, but the effect of increased distance from the arc upon the form of the saturation curve is shown in Fig. 6. The upper curve was taken when the body B was only 24 cm. from the arc, and the time required for the vapors to reach B was 2.5 seconds. In the case of the lower curve all the conditions were the same except that the tube leading

[1] See McClelland, Phil. Mag., 46, p. 29, 1898.

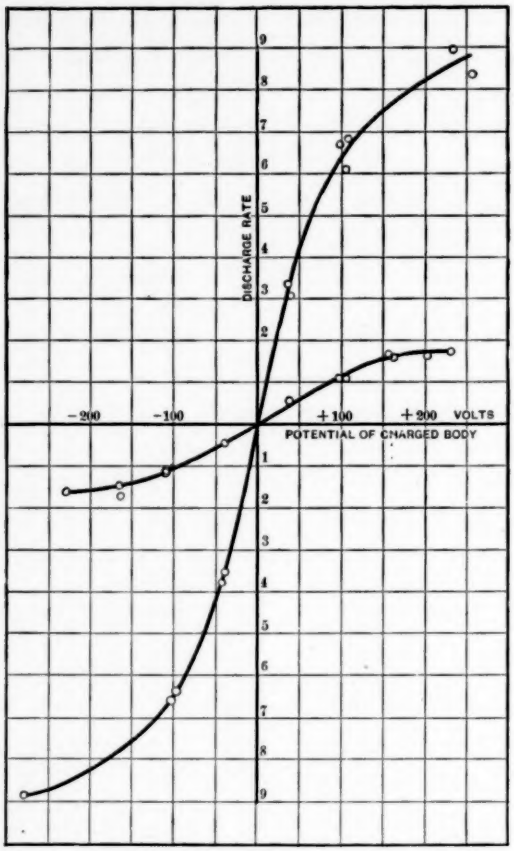

Fig. 6.

from the arc to B was lengthened, so that the time was increased to 9 seconds. Numerical data are given in Tables III. and IV.

TABLE III.

Same conditions as stated in Table I.

Potential (volts).	Discharge current. (Arbitrary units.)	Potential (volts).	Discharge current. (Arbitrary units.)
+104	61	− 42	35
+107	68	+ 36	31
−102	66	+ 36	34
+ 98	67	+253	84
− 98	64	+232	89
− 46	38	−280	89

TABLE IV.

Vapor drawn through an iron tube 6 mm. in diameter and 24 cm. long, and then through a brass tube 2.5 cm. in diameter and 79.5 cm. long. The time required to pass from the arc to B was 9 sec.

Potential (volts).	Discharge current. (Arbitrary units.)	Potential (volts).	Discharge current. (Arbitrary units.)
−166	17	−167	15
+156	17	+257	18
+ 97	11	−270	17
−108	11	−231	16
− 43	4.8	+202	16
+ 37	5.2	+106	11
+160	16.	−107	11

From a mere inspection of the two curves the conclusion might be drawn that they are really of the same form, differing only in the scale of ordinates. This is not quite true, however, as may be shown by computing the ratio of the two ordinates corresponding to a given abscissa. The values of this ratio for different potentials are given in Table V. It will be noticed that the ratio is greater for low potentials than for high. For example, if B is charged to 50 volts the discharge rate is seven times as fast when B is near the arc as when it is at a greater distance. But if B is at a potential of 200 volts the ratio of the two rates is only five to one.

TABLE V.

Potential of B.	Discharge Rate.		Ratio of two rates.	Potential of B.	Discharge Rate.		Ratio of two rates.
	Curve I.	Curve II.			Curve I.	Curve II.	
− 50	4.1	0.6	6.8	+ 50	4.2	0.6	7.0
−100	6.4	1.0	6.4	100	6.4	1.1	5.8
−150	7.5	1.4	5.4	150	7.5	1.6	4.7
+200	8.2	1.6	5.1	200	8.2	1.6	5.1

Unsymmetrical Effects.

In the preceding cases it was found that the rate of discharge did not depend on the sign of the charge. However, when the tube m extended some distance inside the arc enclosure, as indicated in Fig. 7,

an unsymmetrical effect was obtained, that is, positive and negative charges were not discharged at the same rate. When the lower carbon was negative a positive charge on B was discharged more rapidly. If, however, the current was reversed, making the lower carbon positive, negative electricity was discharged more rapidly. Unless the end of the tube m is several centimeters above the arc this unsymmetrical effect was always obtained.

Fig. 7.

The curves shown in Fig. 8 illustrate the results obtained when the tube m projected below the arc. The tubes L and m were of glass, L being 20 cm. long and 2.5 cm. in diameter. The center of the glass tube m was about 2 cm. from

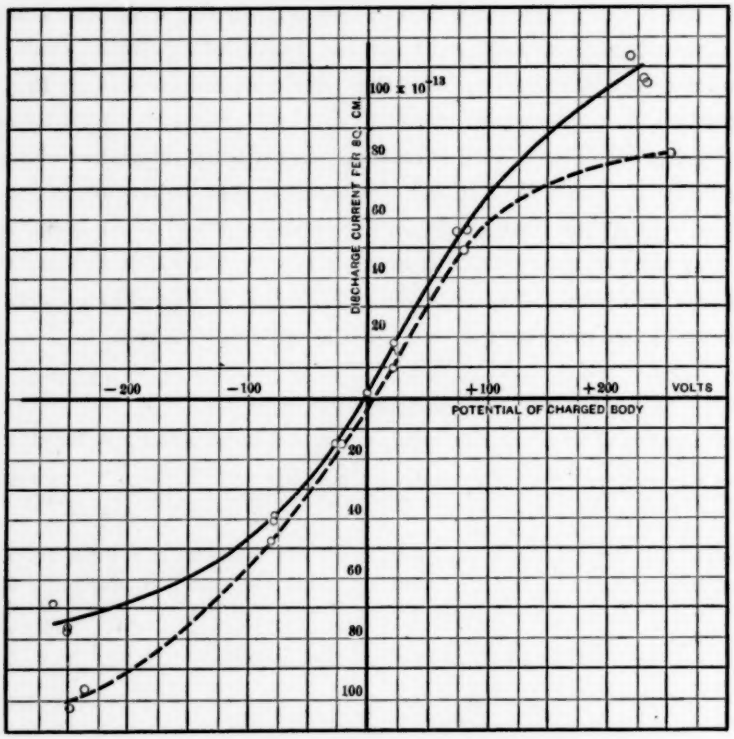

Fig. 8.

the arc, and in the case corresponding to the continuous curve projected 0.5 cm. below a horizontal plane through the arc. In

the case of the observations shown in the broken line curve it projected about 1.2 cm. below. These distances however are only approximate, the burning away of the carbons causing a shifting of the position of the arc. In the first case, the continuous curve, the positive carbon was above and grounded. In the second case the lower carbon was connected to the positive pole and grounded. However, it seemed to make no difference which carbon was grounded.

Inside the glass enclosure of the arc there probably exist convection currents; near the carbons the gases would be rising, while near the glass enclosure they would be descending. If so, the gases which rise up along the lower carbon are probably ionized. When, for example, the lower carbon is negative, positive ions would be attracted and negative ions repelled, thus causing an excess of negative ions in the outer layers of the rising gases. The gases that pass up the glass tube *m* would in this case have an excess of negative ions.

Other explanations suggest themselves; for example, the presence of fine particles shot off from the carbons. It is the intention of the writers to conduct further experiments along this line.

Another instance of asymmetry was found which was due to an entirely different cause. A brass cylinder, *C*, was placed concentrically in the brass tube *L*, but insulated from it. The outer tube *L* was in this case 23 cm. long and its inside diameter 2.35 cm. The length of *C* was 20 cm. and diameter 2.0 cm. *m* was of glass. It is seen that under these circumstances the vapors from the arc had to pass through a rather long and narrow circular aperture. When *C* was kept charged either positively or negatively, *L* being grounded, the rate of discharge from *B* was very much reduced. That is, the ions gave up their charges to the charged walls close to which they must go. But when *C* and *L* were *both* grounded it was found that negative electricity was discharged much more rapidly than positive. There has been found evidence to show[1] that negative ions have a greater velocity than positive ions in the gases from flames and in gases exposed to X-rays. From this it follows[2]

[1] See McClelland, Philosophical Magazine, 46, p. 29, 1898; also Zeleny, Phil. Mag., 46, p. 120, 1898.

[2] See Zeleny, l. c.

that the ions are not of the same size, the negative being the smaller. Negative ions would then diffuse more rapidly even in a field of no force. It is in this way that the tendency of a metal to take a negative charge from Roentgenized air is explained. If this difference between the two kinds of ions also exists in the case of the arc vapors, then the negative ions would give up their charges more readily to the body C and the concentric wall of the outer tubing. After the gas had passed C there would therefore be an excess of positively charged ions, and negative electricity on B would be discharged more rapidly than positive.

Effect of Moisture.

Early in the course of the experiments above described it was found that the presence of moisture in the neighborhood of the arc exerted a marked influence upon the discharging power of the vapors. This fact, whose full significance we have not yet been able to explain, was detected in the following manner:

In our early attempts to obtain steady conditions the arc was placed in a large iron enclosure, the vapors being drawn out through a tube at the top. Measurements made with this apparatus showed that a considerable time was required before steady conditions were reached. When the arc was first started the vapors possessed great discharging power. This steadily diminished, however, and reached a constant value only at the end of an hour or more. The iron enclosure containing the arc was not quite air-tight, but the entrance of air was by no means easy. It therefore occurred to us that the change in the properties of the vapors might be due to the fact that the oxygen of the air originally in the enclosure was being gradually consumed, and that the ionization of the vapors gradually decreased in consequence. To test this matter the conducting power of the vapors was determined while oxygen was being forced into the enclosure. It was found that a very noticeable increase in the rate of discharge immediately resulted, even though the oxygen was not carried directly to the arc.

This result seemed to bear out our first explanation of the matter; but since the oxygen used had been kept in a reservoir where it was in contact with water, it seemed desirable to repeat the

experiments with the dry gas, so as to exclude the possible effect of moisture. Oxygen from the same reservoir was therefore carefully dried by passing it through several sulphuric acid bottles and stored in a rubber bag. This dry oxygen was found to be entirely without effect, while moist oxygen, injected into the enclosure in the same manner, produced a marked increase in the rate of discharge.

Experiments in which wet and dry air were used gave similar results. Two rubber bags were filled with air, which in one case had been carefully dried with sulphuric acid, and in the other case had been saturated with moisture by bubbling through water. These bags were of practically the same size and were subjected to the same pressure. It was then found that the moist air produced a great increase in the discharging power of the arc vapors, while the dry air produced either no change or, in some instances, a slight decrease.

The effect did not result from any change in the insulation of the apparatus due to the moisture, for, upon stopping the arc, the discharge was found to cease. No leakage could be detected even when the moist air was passing through the apparatus as rapidly as before.

The increase in the rate of discharge produced by the presence of moisture was independent of the sign of the initial charge.

Similar experiments with wet and dry air were tried when the arc was enclosed as shown in Fig. 7. The results obtained were the same as those just described in case the tube leading to the body *B* was short; but when the vapors passed from the arc through a tube 50 cm. long the introduction of the moist air was without effect.

It was frequently observed that a peculiar gray dust or ash was formed in the arc and deposited upon the interior of the connecting tubes and upon the discharge body itself. At the close of one set of experiments with moist air this deposit was found to be unusually thick, and it seemed possible that the whole effect might be due merely to the condensation of moisture in this non-conducting layer. The effect was found to be equally strong, however, when the tubes and the discharge body had been freshly cleaned.

A striking characteristic of the experiments with moist air and oxygen was the quickness with which the effect followed the cause.

The increased discharge rate was noticed in all cases within a few seconds after the moist air had been introduced; and when the supply of moisture was cut off the return to the normal rate of discharge was equally prompt. In making there observations the body B, having been first charged, was insulated, and its potential was observed every ten seconds. During such a set of readings the potential of B gradually fell, and in consequence the discharge rate, which was measured by the fall of potential during a ten seconds' interval, became gradually less. The effect of introducing moist air during the progress of a set of readings was to overcome this decrease in the rate completely, so that the body B was discharged at an increased rate even when the potential was less than at first. Fig. 9 gives a graphical representation of such a series of observa-

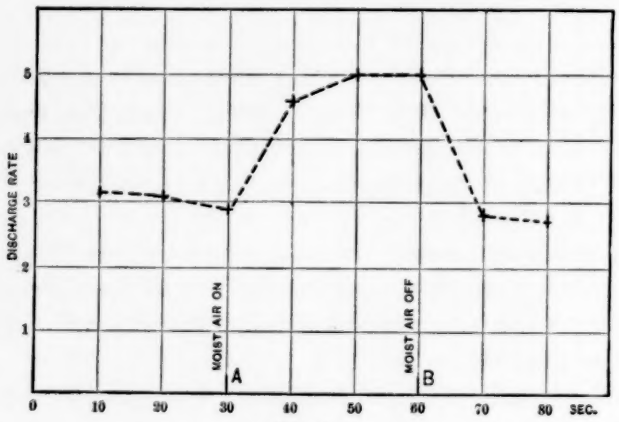

Fig. 9.

tions. The ordinates represent successive values of the discharge rate, as measured by the fall of potential in a ten seconds' interval; the abscissa in each case shows the time at which the observation was made. Moist air was introduced into the enclosure at the time corresponding to the point marked A, and the supply was stopped at the time corresponding to B. A similar series of observations with dry air is represented in Fig. 10. In this case the decrease of the rate is explained by the fact that the air admitted during the time AB was drier than the air from the room which entered before and after that interval.

All of the effects observed in our experiments with wet and dry air and oxygen are satisfactorily explained upon the assumption that the water vapor is ionized by passing through or near the arc, and that the conducting power thus acquired is greater than that imparted to other atmospheric gases under like conditions. If this explanation is true we must also conclude that the vapor of water loses its ionized condition more quickly than do the other gases contained in the air; for, as already stated, the effect of moisture is seen only when the arc is close to the body *B*.

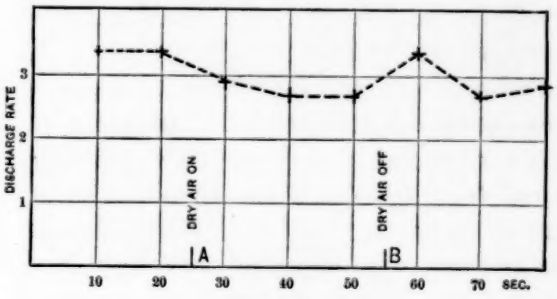

Fig. 10.

While the assumption of a high degree of ionization in the case of water vapor offers a satisfactory explanation of the observed phenomena, we do not feel that the experiments are sufficient to exclude the possibility of ascribing the effect to other causes. It is conceivable, for example, that the mere presence of dust particles might lead to the same increase in the discharging power; for each particle of dust or carbon would form a nucleus upon which moisture might condense, and these particles might then act as carriers for the charge upon *B*. Still other explanations of the phenomena readily suggest themselves. As yet, however, we have not found any direct experimental confirmation of either explanation.

Conclusion.

The results of the above experiments, which are to be looked upon as preliminary, may be briefly summarized as follows:

1. The vapors from the carbon arc possess the power of discharging electrified bodies with which they are brought in contact. In

general the electrical properties of these vapors are similar to those of gases that have been acted on by X-rays, or to the gases from a flame. Except at low potentials the rate of discharge is not proportional to the potential, but approaches a limiting value as the potential is raised.

2. This discharging power is retained even after the vapors have been passed through long tubes of glass or metal, and lasts for at least ten seconds.

3. When caused to pass between a charged conductor and one that is grounded the vapors in large part lose their conducting power. A similar result is obtained by passing the vapors through loosely packed asbestos wool.

4. After passing between two grounded conductors, these being only a short distance apart, the vapors are found to discharge a negatively electrified body more rapidly than one charged positively. In this respect their behavior is similar to that of gases that have been ionized by the action of X-rays. The explanation of the phenomenon is probably that suggested by Zeleny, namely, that the negative ions diffuse more rapidly than the positive ones.

5. Positive and negative charges are in general dissipated by the vapors with equal rapidity. But experiments made with a vertical enclosed arc show that gases taken from near the lower carbon have unequal discharging powers for the two electricities; in this case that charge which is of the same sign as the lower carbon is dissipated less rapidly. This is true whether the lower carbon is positive or negative; and the effect is not altered by connecting either carbon with the earth.

6. If air or oxygen that has been saturated with water vapor is introduced into the enclosure containing the arc, the conducting power of the arc vapors is greatly increased. But this effect can no longer be observed when the body to be discharged is at a considerable distance from the arc.

A COMPARISON OF THE ELECTROMOTIVE FORCE OF THE CLARK AND CADMIUM CELLS.

By S. N. Taylor.

WHEN this investigation was begun at the suggestion of Professor Webster, no absolute determination of the E. M. F. of the cadmium cell had been published and although the Reichsanstalt has since published results[1] it seems worth while to publish this also as an entirely independent determination.

This work was performed at the Physical Laboratory of Clark University and completed June, 1896. All current measurements were made upon a newly constructed electro-dynamometer, described hereafter, for which the constant had to be calculated, but as there were reasons for believing that the method used in calculating this constant was not satisfactory as applied to this instrument, these results have been held back until further calculations of the constant could be completed.

The careful determinations made by Lord Rayleigh,[2] Glazebrook,[3] Carhart,[4] Kahle,[5] and others have fully established the merits of the Latimer Clark standard cell. By them it has been shown that the cell can be made so that under favorable conditions it will not vary in E. M. F. more than one part in a thousand, even when made by different persons and of material obtained from various sources. The cell is easily made, and with proper care maintains its E. M. F. indefinitely providing the temperature remains unchanged.

The one serious drawback is its large temperature coefficient, which causes a variation of about .001 volt for every degree change in temperature. Moreover, the temperature coefficient may not be

[1] Jaeger and Wachsmuth, Das Cadmium Normalelement, Annalen Chem. und Phys. 59 (1896).

[2] Lord Rayleigh and Mrs. Sidgwick, Phil. Trans., 1884 and 1885.

[3] Glazebrook and Skinner, Phil. Trans., 1892.

[4] Carhart, Phil. Mag., Nov., 1892.

[5] Kahle, Annalen, 1894.

the same for different cells, or may be different at different temperatures even in the same cell.

Thus the temperature coefficient of any cell can be exactly determined only by experiment on that particular cell, and should be ascertained for all temperatures to which the cell is liable to be exposed. Moreover the change of temperature in the cell can not be detected easily and accurately, and hence there is always some doubt as to the exact E. M. F. of a Clark standard under any condition.

The cadmium cell invented by Mr. Edward Weston has attracted considerable attention, for the reason that its temperature coefficient is extremely small. The solubility of cadmium sulphate is practically constant for a comparatively wide range of temperature. It is probable that the constancy of the cadmium cell is largely due to this fact. Two questions, therefore, arise with reference to this cell: First, is its E. M. F. invariable when the cell is made by different individuals and of materials obtained from various sources? Second, what is its E. M. F.? With the purpose of answering these questions, this investigation was begun December, 1893, and, in connection with work on other problems, was continued until June, 1896.

CONSTRUCTION OF CELLS.

About twenty cells of each kind were made for the purpose. The Clark cells were made according to the latest instructions given by the English Board of Trade in the Philosophical Transactions of 1892, the adopted test-tube form being the kind used.

Some of the cadmium cells were made in the H-form; the others were of the inverted Y-form. They were made at different times in groups of from five to eight cells in a group. A description of those made March, 1895, will indicate the manner in which all the cells were made, there being only slight differences between the different groups. In this group all the cells were made in the H-form, and were numbered from 7 to 14 inclusive.

The mercury was thoroughly cleansed with acids and distilled in vacuo a short time before the cells were set up. The crystals of cadmium sulphate ($CdSO_4$) and mercurous sulphate (Hg_2SO_4) and the rods of cadmium were all bought of Eimer and Amend, in New York, as chemically pure. To form the cadmium amalgam six

parts by weight of mercury were mixed with one part of cadmium and dissolved at a gentle heat. The mixture became solid when cold. The cadmium sulphate solution was formed by dissolving 35.4 grams of cadmium sulphate crystals in 60 grams of distilled water the temperature of which was kept below 60° C., crystals being formed on cooling.

Especial care was taken in preparing the mercurous sulphate solution. Forty grams of the dry mercurous sulphate crystals were weighed out and then washed three times in distilled water by decantation. After the first washing the salt was slightly yellow, but neutral to litmus paper. After the second and third washing it was white and gave no acid reaction. Having been washed the salt was drained on filter paper for half an hour till apparently quite free from water. It was then placed in a mortar and enough of the dry cadmium sulphate crystals were added to form a paste somewhat stiffer than cream when all had been finely ground together. The bottle from which the cadmium sulphate was taken, having been previously weighed, was then weighed again, and it was found that 23 grams of the cadmium sulphate had been used with the mercurous sulphate in forming the paste.

The cells were set up in a manner similar to the Clark cells. In one tube there was placed a quantity of cadmium amalgam covering the platinum wire about a centimeter deep, introduced while warm and paste-like. This becomes hard and fixed when cool. Above this is a layer of cadmium sulphate crystals reaching up to the horizontal cross-tube. In the other tube the platinum wire is covered with pure mercury which serves as the positive electrode. Above the mercury and reaching up to the cross-tube is placed the thick paste of mercurous sulphate. The remaining space up to the corks is filled with the concentrated solution of cadmium sulphate. The tubes are then sealed above the corks by means of a cement made of beeswax and rosin.

Comparison of Cells.

The method of comparing the cells, one with another, was a modification of the potentiometer method used by Kahle, and was as follows:

The current from a single storage cell A, Fig. 1, passes through an ordinary resistance box B' and through a wire resistance R, made of German silver with sliding contact capable of continuous variation for fine adjustment. At the mercury commutator M the circuit divides. The first, or **B**-branch, passes successively through the resistance box B, the resistance wire D, the connecting wire F back to M. The second, or **W**-branch, passes successively from M through the transfer switch S, the variable resistance R', the galvanometer G, back again to S, thence through the cell W to M, where it meets the **B**-branch and proceeds to A. The resistance box B has its coils submerged in kerosene oil so that their temperature can be determined more accurately. D is a German-silver wire 1,122 millimeters long, stretched tightly over a boxwood meter-bar. The resistances of both B and D have been carefully measured in international ohms and their temperature coefficients determined.

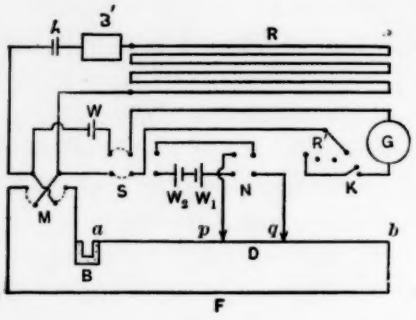

Fig. 1.

W is a standard cell, either a Clark or Weston, and is connected in opposition to the storage cell A.

As the current then passes from A, if the resistance in B is properly adjusted, the E. M. F. of W, between the extremities of the **W**-branch, will exactly counterbalance the difference of potential due to A between the extremities of the **B**-branch, and there will be no deflection of galvanometer G when the key K is closed. But increasing the resistance in B will, if A remains constant, have the same effect upon the potential difference around that branch as decreasing the resistance in R. Accordingly we may choose whatever resistance in B will answer our purpose best and regulate the potential difference around the branch to balance W by properly adjusting the resistance in R.

When equilibrium has thus been obtained then

$$E_w : E_D :: B : D$$

where E_w denotes the E. M. F. of the standard cell W,
E_D the difference of potential between a and b,
B the total resistance of the **B**-branch
and D the total resistance of the wire D between its extremities a and b.

Another portion of the potentiometer consists of a third branch circuit which we may call the **N**-branch.

It starts from p a movable contact upon the wire D and passes successively through the reversing commutator N, the standard cells W_1 and W_2, which are to be compared, then through the transfer-switch S, to the galvanometer G back to N and finally to q which is another movable contact upon the wire D. The galvanometer circuit is so connected at S that it can be thrown instantly into either the **N** or the **W**-branch. The two cells W_1 and W_2 to be compared are connected in opposition to each other and if they are exactly equal in E. M. F. they will balance each other and produce no current through the galvanometer, when p and q are at the same point on D. If, however, E_1 the E. M. F. of W_1 is greater than E_2 which is that of W_2, we can find two points upon D such that the difference of potential between p and q shall be exactly equal and opposite to the difference between E_1 and E_2.

When equilibrium has been thus obtained the difference between E_1 and E_2 is measured in terms of the standard cell W, that is:

$$E_1 - E_2 = \frac{nE_w D}{lB} = nk,$$

where E_w = the E. M. F. of cell W;
E_1 = the E. M. F. of cell W_1;
E_2 = the E. M. F. of cell W_2;
n = the number of mms. between p and q;
l = total length of D in millimeters;
D = resistance of D between a and b;
B = total resistance of the **B**-branch and $k = \frac{E_w D}{l B}$.

The resistance at R' consists of a few coils varying from 0 to 50,000 ohms, but their actual resistance need not be known, neither is it necessary to know the resistance of the galvanometer since

the method of no deflection is used. Care was always taken, however, never to close the galvanometer circuit without including a high resistance at R', unless it was first known that the system was at equilibrium, for it is important that no current shall pass through any of the standard cells. Measurements by means of this apparatus were limited in extent only by the sensitiveness of the galvanometer, for by taking the resistance in B large enough, k can be made as small as we please. Thus it was possible to detect differences of potential even as small as three millionths of a volt with a considerable degree of accuracy.

USE OF THE POTENTIOMETER.

In using the potentiometer the best results were obtained as follows:

The storage cell A was first charged to its fullest capacity and then discharged for five or six hours continuously through the **B**-branch with the resistances of the entire circuit adjusted as they were to be used in the measurements. By doing this the circuit had time to acquire a normal temperature, but most important of all the storage cell gradually assumed a condition which would remain almost perfectly constant so that no change whatever in potential could be detected for short intervals of time. It was found advisable, moreover, not to interrupt the current any more than necessary, even to reverse the commutator M, for such interruptions tend to effect the constancy of the cell A, especially if long continued.

These precautions having been taken, final adjustments were made in R to balance exactly the potential due to W, no deflection of the galvanometer being detected even when all the resistance at R' had been cut out. The galvanometer was then transferred to the **N**-branch which contained the cells W_1 and W_2, the **W**-branch being open at the time.

The contact piece p having been placed at the middle point 500, q was moved along D until this system also was at equilibrium. The switch S could then be rapidly transferred back and forth between the branches N and W, making any necessary adjustment at R, if A had changed during the interval, until it was known that the potential in both the N and W branches were balanced at the

same instant. To avoid any error that might be caused by thermal effects, the current in both the B and N branches was reversed, the balancing repeated, and the mean taken. One difficulty which had

TABLE I.

Variations of E. M. F. of Clark and Weston Cells.

	Date of Meas.	March 16, 1895.	March 18, 1895.	March 22, 1895.	April 15, 1895.	April 17, 1895.	April 18, 1895.	June 17, 1895.	October 25, 1895.	May 29, 1896.
	Temp.	18°.8C.	19°.8	20°.0	19°.0	20°.2	20°.0	23°.2	19°.6	20°.0
Cells made Oct., 1894.	C_4				$C_5 + 13.0$	$C_5 + 20.3$	$C_5 + 17.8$	$C_5 + 37.6$	$C_5 + 49.6$	
	C_6							$C_5 + 60.2$		
	C_7				$C_5 + 46.5$	$C_5 + 74.3$	$C_5 + 86.7$	$C_5 + 42.8$	$C_5 + 74.9$	
	C_8				$C_5 - 10.9$	$C_5 - 15.1$	$C_5 - 15.1$	$C_5 - 64.4$	$C_5 - 49.6$	
	C_9				$C_5 - 11.5$	$C_5 - 14.2$	$C_5 - 4.5$	$C_5 - 45.9$	$C_5 - 49.6$	
Cells made March, 1895.	W_7	$W_8 - 15.1$	$W_8 - 16.3$	$W_8 - 21.1$	$W_8 + 8.8$	$W_8 + 10.3$	$W_8 + 9.1$	$W_8 + 13.8$	$W_8 + 7.2$	$W_8 + 3.0$
	W_9	$W_8 + 21.1$	$W_8 + 24.6$	$W_8 + 12.1$	$W_8 - 5.4$	$W_8 - 4.5$	$W_8 - 4.8$	$W_8 + 4.8$	$W_8 - 7.8$	$W_8 + 1.9$
	W_{10}	$W_8 - 24.5$	$W_8 - 23.9$	$W_8 - 39.2$	$W_8 - 23.6$	$W_8 - 22.3$	$W_8 - 23.6$	$W_8 + 4.2$	$W_8 - 3.0$	$W_8 + 1.9$
	W_{11}	$W_8 - 8.2$	$W_8 + 14.2$	$W_8 + 12.1$	$W_8 + 3.9$	$W_8 + 3.6$	$W_8 + 4.5$	$W_8 + 1.2$	$W_8 - 2.4$	$W_8 + 7.6$
	W_{12}	$W_8 + 64.3$	$W_8 + 74.0$	$W_8 + 40.8$	$W_8 + 19.3$	$W_8 + 13.9$	$W_8 + 16.0$	$W_8 + 12.6$	$W_8 + 11.1$	$W_8 + 14.1$
	W_{13}	$W_8 + 72.5$	$W_8 + 5.5$	$W_8 - 3.0$	$W_8 - 2.7$	$W_8 - 3.0$	$W_8 - 3.0$	$W_8 + 3.0$	$W_8 - 5.7$	$W_8 + 1.9$
	W_{14}	$W_8 + 7.6$	$W_8 - 3.0$	$W_8 - 13.8$	$W_8 - 8.5$	$W_8 - 7.0$	$W_8 - 9.1$	$W_8 - 7.2$	$W_8 - 3.0$	$W_8 + 4.2$
Cells made May, 1895.	W_{15}							$W_8 + 27.1$	$W_8 + 22.3$	$W_8 + 7.6$
	W_{16}							$W_8 + 18.4$	$W_8 + 7.5$	$W_8 + 2.7$
	W_{17}							$W_8 + 25.5$	$W_8 + 9.6$	$W_8 + 5.7$
	W_{18}							$W_8 + 30.7$	$W_8 + 15.1$	$W_8 + 4.6$
	W_{19}							$W_8 + 18.4$	$W_8 + 5.1$	$W_8 \pm 5.6$

to be overcome was the change in the position of the galvanometer zero caused by the passing of electric street cars some 300 feet distant. It was found necessary to make some of the final measurements between 12:30 and 5:30 a. m., when the street cars had stopped for the night.

Table No. 1 gives a series of potentiometer measurements made on a number of Clark and cadmium cells, where each cell is compared to one of its own kind taken as a standard and the differences are expressed in hundred thousandths of a volt.

When the cells were first set up they differed somewhat from one another. This was due perhaps to my inexperience in setting up cells. After about a month, however, they attained their normal value which is common to all. I have no reason for supposing that this value has changed during the time of the experiments or since then.

The variations between different measurements (Table I) made upon the same cells, after the normal has been reached, are due, to some extent no doubt, to errors in reading; but I think they are chiefly due to the variations of the galvanometer zero, caused by the electric street-railway, for these tests were all made during the day time while the cars were running. Deviations due to this cause have been found sufficient to account for the above discrepancies.

THE ELECTRO-DYNAMOMETER.

The potential measurements in Table I are given simply in terms of a certain cell taken as the standard; but to measure in absolute units the actual E. M. F. of that or any other cell another method must be used. The method used for this purpose was to measure the current which, when passed through a known resistance, produced a potential equal to the E. M. F. of the cell in question.

The apparatus was a current-weighing device, or electro-dynamometer similar to the one used by Lord Rayleigh in determining the electro-chemical equivalent of silver.[1] It consists of three parts, a balance, a movable coil suspended from the beam of the balance,

[1] Lord Rayleigh and Mrs. Sidgwick, Phil. Trans., 1884 and 1885.

and two parallel, co-axial, fixed coils between which the suspended coil oscillates. The form upon which the fixed coils were wound was a cup-shaped cylinder made of plaster of Paris. The vertical section of this is shown in Fig. 2. Plaster of Paris was found to be more nearly neutral magnetically than any other appropriate substance,[1] except, perhaps, certain particular specimens of glass, or marble, and not less so than even these. Glass may be either magnetic or diamagnetic, depending upon the particular specimen considered. Both glass and marble are, however, difficult to manipulate, and expensive, but plaster of Paris is inexpensive and works easily under a sharp tool. To form the inner cavity of the cylinder a wooden core, mounted on an iron axle, was turned to the desired shape, polished and then coated with a thick oil, so that the plaster would not adhere to it. It was then placed in position in the mould and the soft plaster poured around it. When the plaster had become hard the core was loosened from the casting, then replaced and clamped in position by means of a nut on the end of the iron axle. This core served as a support for the casting when it was being turned in the lathe. It also provided an accurate center for the cylinder while the measurements were being made and was a convenient mounting while the coils were being wound.

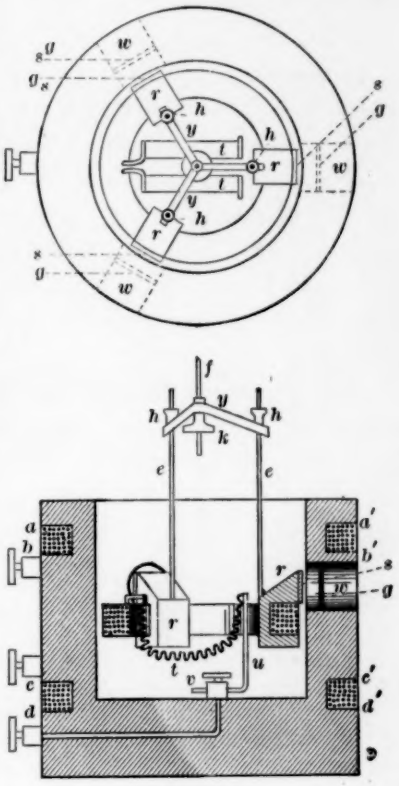

Fig. 2.

Two grooves (*ab* and *cd*, Fig. 2) were turned in the casting in

[1] Determinations made by Mr. A. P. Wills by the method described in Phil. Mag., May, 1898; also PHYSICAL REVIEW, April, 1898.

which to wind the fixed coils. Great care was taken with these channels to make them exactly co-axial and equal in all dimensions. The cylinder was then soaked for forty-eight hours in linseed oil containing a small quantity of liquid dryer and allowed to harden for several weeks.

The object of the oil was to prevent the plaster from absorbing moisture and it was thought that in time it would tend to make the plaster still harder. It may be that paraffine would have been better for this purpose, but it was feared that the application of hot paraffine might crack the plaster. The casting having become hard, and all porous places having been filled with a hard cement, the cylinder was again mounted upon the core in the lathe and carefully surfaced to remove any unevenness which might have been produced by the cement or by the action of the oil.

TABLE II.

Measurements of Upper Coil.				Measurements of Lower Coil.			
Number of Layer.	No. of Turns in Layer.	Mean External Diam. of Layer.	Mean Central Diameter of Layer.	Number of Layer.	No. of Turns in Layer.	Mean External Diam. of Layer.	Mean Central Diameter of Layer.
(Bot. of	Groove.)	197.579 mm.		(Bot. of	Groove.)	197.981 mm.	
1	15	199.964 "	198.7885 mm.	1	15	200.066 "	199.0235 mm.
2	15	201.629 "	200.8135 "	2	15	201.936 "	201.0010 "
3	15	203.730 "	202.6795 "	3	15	203.845 "	202.8905 "
4	15	205.564 "	204.6470 "	4	15	205.880 "	204.3675 "
5	15	207.404 "	206.4840 "	5	15	207.948 "	206.4190 "
6	15	209.370 "	208.3870 "	6	15	209.792 "	208.8700 "
7	15	211.220 "	210.2950 "	7	15	211.743 "	210.7675 "
8	15	213.134 "	212.1770 "	8	15	213.704 "	212.7273 "
9	15	215.022 "	214.0780 "	9	15	215.647 "	214.6755 "
10	15	216.934 "	215.9780 "	10	15	217.502 "	216.5745 "
11	15	218.872 "	217.9030 "	11	15	219.499 "	218.5005 "
12	15	220.900 "	219.8860 "	12	15	221.363 "	220.4310 "
13	15	222.801 "	221.8505 "	13	15	223.409 "	222.3860 "
14	15	224.826 "	223.8135 "	14	15	225.289 "	224.3490 "
15	15	226.628 "	225.5270 "	15	15	227.292 "	226.2905 "
Total	$225=N'$	3395.611 "	3183.5075 "	Total	$225=N''$	3401.906 "	3189.2695 "

Mean diameter of coil	$=2A'=$	212.2238 mm.	Mean diameter of coil $=2A''=$ 212.6180 mm.
" radius of coil	$=A'=$	106.1169 "	" radius of coil $=A''=$ 106.3090 "
" radial width of coil	$=2H'=$	14.5245 "	" radial width of coil $=2H''=$ 14.6555 "
" axial " "	$=2K'=$	17.6620 "	" axial " " $=2K''=$ 17.4420 "
Mean distance between			Upper and Lower Coils $=2B=$ 116.1725 "

When the cylinder had been thus prepared, while still clamped upon the core and axle, it was mounted on a suitable frame and supported in a rigid manner near the cathetometer in such a way that its dimensions could be measured in all positions, either vertical or horizontal. These conditions also applied during the process of winding. The circumference of the cylinder was marked off into six equal parts and the diameters of both grooves were measured at each of these points. In like manner the width of the grooves and their distance apart was measured at the same points, the cylinder being in a vetical position. Several independent measurements were taken in each position and their mean results are given in Table II.

Method of Winding.

A coil of No. 18 double-silk-insulated copper wire was wound in each of these grooves, the wire being passed through a bath of hot paraffine during the process of winding. It was thought that the length of the wire upon each coil could be accurately measured in two ways : first by direct measurement before the winding was done, and second by measuring the diameter of each layer as soon as it had been completely wound. With the purpose in view of making measurements by the first method, the wire was stretched across the room and arranged so that it was supplied from the spool with a uniform tension. The measurements by means of this method, however, were not successful because the wire stretched under tension, therefore a description of the apparatus and methods thus employed will not be given here.

To avoid errors in counting the turns of wire, a long rod was attached to the axle of the cylinder turning with it and a cord was wound upon the rod at the same time that the wire was wound upon the coil. A mark was placed upon the cord on the rod as soon as each layer of wire was completed on the coil. These turns could be counted when all the winding had been finished, thus there is no probability that error occurred in counting.

As soon as a layer of wire had been wound upon the coil, the diameter of the layer was measured by means of the cathetometer. The process was repeated for each layer, the measurements in every case being taken in the same positions as those formerly adopted in

finding the dimensions of the grooves. As in the preceding measurements, several determinations were made in each position and the mean of these for every layer, together with the number of turns in each is given for both the fixed coils in Table II. As soon as the winding of the coils was completed, the outer end of each was fastened to a binding-post fixed in the plaster, and the inner ends were twisted together and soldered on the inner surface of the cylinder. At three points 120 degrees apart and a little above the line midway between the two fixed coils a hole was made through the plaster, about three centimeters in diameter. Into each of these holes a piece of plane glass *g*, Fig. 2, was fitted which had engraved upon it two diameters at right angles. The purpose of these cross-lines was to afford a means of adjusting the suspended coil to its proper position midway between the two fixed coils. The method of locating these cross-lines will be given later.

THE SUSPENDED COIL.

In order that the movable coil might be as light as possible it was made without spool or framework, but for the purpose of winding, a form was made of two flat pieces of maple bolted together and mounted upon an iron axle. This was turned in the lathe to the desired shape, and in such a manner that the plane separating the two pieces of wood lay within the groove intended for the coil of wire, and parallel with it, so that when the coil had been wound in the groove, the two wooden discs could be separated and the coil removed from them without being damaged. Paste-board rings, or washers, saturated with paraffine were used to keep the wire from sticking to the wood and to help the parts to separate readily when the coil had been wound.

This coil, like the others, was made of No. 18 double-silk-insulated copper wire, but unlike them it contained sixteen layers of wire and each layer contained sixteen turns. It differed from them also in that during the process of winding the wire was passed through a path of shellac varnish instead of paraffine, and each layer was coated with shellac and allowed to harden thoroughly before the next layer was put on. The same measurements were made upon this coil that were made upon the others, but after the com-

pleted coil became dry it was baked in an oven for 24 hours to harden the shellac. During the baking, the wooden coil, although thoroughly seasoned, shrunk somewhat and the coil changed form with it, so that the previous measurements had to be discarded and others made. Diameter measurements were taken at every 25 degrees and the axial measurements were taken at the same points. The coil being entirely exposed and perfectly rectangular in cross-section these measurements were possible and were taken by means of the cathetometer as before. The measurements are given in Table III.

TABLE III.

DIMENSIONS OF MOVABLE COIL.

Diameter Measurements.			Axial Measurements.			
Place of Measm't.	Outer Diameter.	Inner Diameter.	Place of Measm't.	Axial Width.	Place of Measm't.	Axial Width.
MM'	159.776 mm.	125.634 mm.	M	18.304 mm.	M'	18.200 mm.
NN'	159.640 "	126.256 "	N	18.016 "	N'	17.952 "
OO'	160.154 "	126.262 "	O	18.404 "	O'	18.432 "
PP'	160.102 "	126.058 "	P	18.440 "	P'	18.362 "
QQ'	159.606 "	125.902 "	Q	18.160 "	Q'	18.236 "
RR'	160.210 "	125.658 "	R	18.192 "	R'	18.320 "
SS'	159.512 "	125.946 "	S	18.268 "	S'	18.384 "
Total	1119.000 "	881.716 "	Total (=	127.784 + 127	.886) =	255.670 "
Mean	159.857 "	125.959 "		Mean =		18.262 "

	mm.		mm.
Mean diam. of coil	$= 2a =$ 142.908	Mean axial width of coil	$= 2k =$ 18.262
" radius "	$= a =$ 71.454	Number of layers in coil	= 16.
Mean radial width	$= 2h =$ 16.949	Number of turns in each layer	= 16.
	Total number of turns $= n =$ 256.		

ADJUSTMENT OF THE SUSPENDED COIL.

As soon as all the measurements had been made the movable coil was wrapped with silk ribbon and at equal distances from one another three blocks of hard rubber (r, Fig. 2) were tightly fitted to it and fastened with shellac. Upon the upper surface of these blocks facing outward was placed a little mirror s marked with two fine lines at right angles. These cross-lines were placed in such a position that when the movable coil was suspended midway between the two fixed coils and co-axial with them, the cross-lines would

coincide with similar lines on the glass discs g fixed in the three adjustment holes w.

These three adjustment or sight holes, and the cross-lines in them were located in the following manner. The position of each hole was first located roughly by means of dividers and the openings bored through the plaster. Then the cylinder was carefully centered upon the circular dividing engine, which had been leveled near the cathetometer. Concentric with the cylinder a plumb-line extended down below the adjustment holes and located the axis of the cylinder. When one of the glass discs had been inserted the dividing engine was rotated upon its axis until the vertical line of the disc coincided with the plumb-line back of it as seen through the telescope of the cathetometer. The angle on the dividing engine was then noted, and the position of the intersection of the cross-lines of the disc, together with the position of the fixed coils, was measured by means of the cathetometer. The intersection of the cross-lines was thus made to coincide as nearly as possible with the median line between the fixed coils and the true deviation from it measured.

The dividing engine was then rotated through 120 degrees, and the telescope of the cathetometer again sighted upon the plumb-line. The vertical line of the second disk was now placed so that it coincided with the plumb-line as before. The position of the horizontal line with reference to the fixed coils was again measured and the median line found. The third pair of cross-lines was adjusted in like manner. Having thus found the distance of the fixed cross-lines from the median line, it is known how far the cross-lines of the mirrors must be from the mean plane of the suspended coil, in order that the two sets of cross-lines shall coincide when the latter coil is equi-distant from the other two. The position of the mirrors was found in the same way as that of the discs. The movable coil was centered upon the circular dividing engines, the angles measured off and the cross-lines properly placed, as in the former case.

THE BALANCE AND ADJUSTMENTS.

The balance is one made by Becker's Sons, Rotterdam. It is very sensitive, has a beam of 45.5 cms. between the extreme knife-

edges and is capable of weighing 1,000 grams. It is placed upon a marble slab supported by a heavy wooden framework about 76 cms. high, which stands upon a massive stone pier in a dark interior room of nearly constant temperature. The cylinder with the fixed coils of the electro-dynamometer stands upon the pier under one end of the balance-beam, and is carefully leveled by means of leveling screws attached to a small marble slab upon which the cylinder rests. A phosphor-bronze wire *f*, Fig. 2, passes from the end of the balance-beam through a hole in a large slab to the center of a kind of tripod *y* having a leveling adjustment *h* at each end of its three branches. From the extremity of each of these branches another wire *e* connects to one of the hard-rubber blocks *r* on the suspended coil, thus forming the means of suspension of the coil.

External connections are made with the suspended coil in the following manner:

The two free ends of the coil, covered with rubber tubing, extend toward the center and bend at right angles in the plane of the coil, but in opposite directions. Soldered to each of these ends is a strip of very thin copper foil *t* about 7 mm. wide, crimped by having been passed between rather finely geared cogs. The other end of the strip *t* is soldered to another wire *u* leading to the binding-post *v*, attached to the bottom of the cylinder and connected to the external binding-post at *d*.

These copper strips are long and sag as much as the space will allow in order to permit free motion of the coil, and are far enough apart to avoid any danger of making contact when the coil moves. When these connections have been made the coil can be suspended and the adjustments made to bring the cross-lines of the mirror *s* and discs *g* to coincide. Horizontal adjustment is secured in the fixed coils by twisting the blocks under the leveling-screws of the cylinder.

Vertical adjustment is obtained in the suspended coil by means of the adjustment screw *k* at the center of the tripod and by means of the leveling screws *h*.

When these adjustments have been made the coils are co-axial and the mean plane of the suspended coil is midway between the mean planes of the other two.

CALCULATIONS.

The attraction between two coils through which the current i is passing is

$$\text{Force} = Nni^2 \frac{dM}{dB}$$

where M denotes the coefficient of mutual induction and N and n denote the number of turns of wire in the fixed and movable coils respectively.

Between two coils of one turn each carrying unit current the attraction is

$$\frac{dM}{dB} = \pi f(A, a, B) = \frac{\pi B}{\sqrt{Aa}} \sin\gamma \{2F_\gamma - (1 + \sec^2\gamma)E_\gamma\}$$

where A denotes the radius of the fixed coil, a the radius of the movable coil, B the distance between them and where F_γ and E_γ are the complete elliptic integrals for the angle γ which is given by the formula

$$\sin\gamma = \frac{2\sqrt{Aa}}{\sqrt{(A+a)^2 + B^2}}.$$

Hence $\frac{1}{2}mg = Nni^2\pi f(A, a, B)$,

or

$$i = \sqrt{\frac{gm}{2Nn\pi f}} = \mu\sqrt{m}$$

where m denotes in grams the difference in attraction produced by reversing the current through the movable coil as determined by means of the balance.

In an electro-dynamometer of three coils, when the upper coil attracts the suspended coil, the lower one repels it, and when the suspended coil is balanced, it is equidistant from the other two. Therefore, the two fixed coils being so nearly identical we may regard the system as consisting of simply one fixed coil and one movable coil, the former containing the total number of turns in the two fixed coils. From the preceding tables we have all the data necessary for calculating this attraction, namely:

Mean radius of fixed coil $A = \frac{1}{2}(A' + A'') = 106.213$ mm.
Mean radius of movable coil $a =$ 71.454 mm.
Mean distance between coils $B =$ 58.086 mm.
Mean radial width of section of fixed coil $H = \frac{1}{2}(H' + H'') = 7.295$ mm.
Mean radial width of section of movable coil $h =$ 8.475 mm.
Mean axial width of section of fixed coil $K = \frac{1}{2}(K' + K'') = 8.776$ mm.
Mean axial width of section of movable coil $k =$ 9.131 mm.
Number of turns in fixed coil $N = \frac{1}{2}(N' + N'') = 450$ turns.
Number of turns in movable coil $n =$ 256 turns.

Following the method of calculation suggested by Lord Rayleigh[1] the following results were derived as the values of f:

$$f(A, a, B) = 3.006815$$
$$f(A + H, a, B) = 2.729883$$
$$f(A - H, a, B) = 3.252198$$
$$f(A, a + h, B) = 3.814970$$
$$f(A, a - h, B) = 2.270557$$
$$f(A, a, B + K) = 2.359961$$
$$f(A, a, B - K) = 4.026890$$
$$f(A, a, B + k) = 2.243498$$
$$f(A, a, B - k) = 4.056446$$
$$\text{Mean } f = 3.123462.$$

From this $\pi f(A, a, B) = 9.812637$ and $\mu = .02083$.

It will be seen from the above results that the various values from which the mean is taken lie too far apart for the method of approximation used by Lord Rayleigh to be applicable in this case.

A more exact, though more complicated, method of approximation is to suppose each coil to be divided into four equal subdivisions from 1 to 8 inclusive (Fig. 3), and to calculate the attraction of each division for every other division with reference to their central points. Denoting

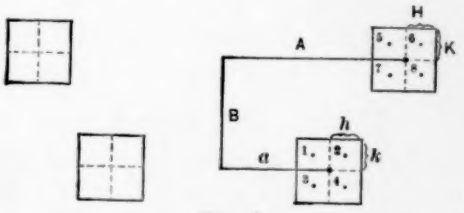

Fig. 3.

[1] Lord Rayleigh and Mrs. Sidgwick, Phil. Trans. (1884 and 1885).

the radial and axial dimensions by the same letters as before and the sections by corresponding subscripts, the calculations were made giving the following results:

$$f(A_5, a_1, B_{15}) = 2.7583813$$
$$f(A_6, a_1, B_{16}) = 2.5037387$$
$$f(A_7, a_1, B_{17}) = 3.1417302$$
$$f(A_8, a_1, B_{18}) = 2.7561738$$
$$f(A_5, a_2, B_{25}) = 3.5436127$$
$$f(A_6, a_2, B_{26}) = 3.2752905$$
$$f(A_7, a_2, B_{27}) = 4.1562665$$
$$f(A_8, a_2, B_{28}) = 3.7172967$$
$$f(A_5, a_3, B_{35}) = 2.3794758$$
$$f(A_6, a_3, B_{36}) = 2.2170942$$
$$f(A_7, a_3, B_{37}) = 2.7443674$$
$$f(A_8, a_3, B_{38}) = 2.4974720$$
$$f(A_5, a_4, B_{45}) = 2.8851441$$
$$f(A_6, a_4, B_{46}) = 2.8345898$$
$$f(A_7, a_4, B_{47}) = 3.5196311$$
$$f(A_8, a_4, B_{48}) = 3.2576402$$
$$\text{Mean } f = 3.0176191$$

From these $\pi f(A, a, B) = \dfrac{dM}{dB} = 9.480122$

and, therefore, $\mu = .02119$.

This constant has since been calculated by Professor Webster and also by M. J. de Perott according to the method of Weinstein[1] involving a development in series. According to their calculations $\pi f(A, a, A) = \dfrac{dM}{dB} = 9.497159$ and accordingly the constant of the instrument $\mu = .02117$ which differs from the constant as determined by the second method by about one part in a thousand.

[1] Weinstein, Wied. Ann., 21, 1884, p. 346.

MEASUREMENTS BY MEANS OF THE ELECTRO-DYNAMOMETER.

The current from a number of accumulator cells, A, Fig. 4, was passed through the resistance S, the dynamometer D and then through resistance R back to A. The resistance S consists of German-silver wire several meters long mounted upon a frame in such a way that all or any part of it can be cut out of the circuit by means of sliding contacts. Resistance R is Legal Ohm, Elliott No. 222, made in the ordinary B. A. Unit form.

Its resistance and temperature coefficient have been carefully determined by means of extended comparisons with standard B. A. Unit No. 6, which according to Glazebrook's comparisons has the value of 1.00003 B. A. units at 13°.2 C. Legal Ohm No. 222 was found by comparison and determination of temperature coefficient to have the value $R_t = .9914829\ (1 + .0002380t)$ international ohms.

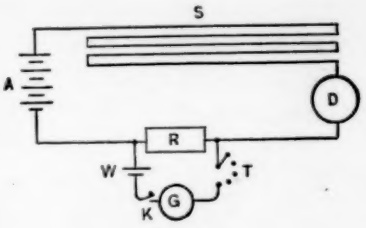

Fig. 4.

By choosing an appropriate number of storage cells A and by adjusting the resistance S, it was possible to obtain any desired current through the circuit, and to vary the potential difference about R at pleasure.

The standard cell W was connected about the terminals of R through a very sensitive galvanometer G, a make-circuit key K and a resistance T, which varied from 0 to 50000 ohms. The E. M. F. of W was then balanced about R and all the resistance at T was then cut out so as to make the galvanometer as sensitive as possible. While this equilibrium existed, the current through R was measured by means of the dynamometer. Hence knowing the resistance of R for the particular temperature, the potential about R is given and also the absolute E. M. F. of the cell W.

It required two observers to make these measurements, one to watch the galvanometer and by slight adjustments at S, to balance the E. M. F. of W about the standard resistance R, the other to make the weighings by means of the dynamometer and balance. I am under obligations to Messrs. Wills, Edmondson, and Sharpe,

and particularly to Mr. W. P. Boynton for assistance in the weighings. If the storage battery A had been brought to a constant normal condition by previous charging and continuous discharging as in the use of the potentiometer, there was no perceptible variation of potential about R for a short period of time providing the current was small. If, however, the current was large there was a slight tendency for the potential to drop very slowly, but this was easily detected by means of the galvanometer. With proper care there was always plenty of time to take several good readings on the balance before any appreciable drop occurred. Readings were taken with the current through the movable coil in both directions and the difference between the weights in the balance-pan under the two conditions is denoted by the symbol m in the formula.

The following tables, IV and V, give a series of measurements taken in this way.

TABLE IV.

E. M. F. of Clark Cells Compared by means of the Electro-Dynamometer.

Cell No.	Temp. of Cell.	Temp. of Coil R.	Mass in grams.	Resistance R at $t°$ C.	$Rt \times \sqrt{m}$	$C_{15} \div \mu$
	T	t	m	Rt	(No. 5)×(4)½	(6)÷[1-a(t-15)]
No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.
Clark 4	19.70	21.10	45.5208	.996462	6.72277	6.74718
" 5	21.08	22.30	45.3958	.996745	6.71570	6.74728
" 6	21.80	22.10	45.3573	.996698	6.71254	6.74756
" 7	21.60	22.50	45.3605	.996793	6.71342	6.74770
" 8	20.50	21.40	45.4761	.996533	6.72022	6.74880
" 9	20.20	22.50	45.4375	.996793	6.71912	6.74613
Mean						6.74744

Here and in the following table C_t is used to denote the E. M. F. of the Clark cells at t °C. and W_t is used to denote the E. M. F. of the Weston or cadmium cells at t °C. The temperature-coefficient is that given by Rayleigh.

From these results, using the value $\mu = .02117$, we obtain $C_{15} = 1.4284$ and $W_{21.7} = 1.0147$. This value for the Clark cell is so far from the usually received values as to lead to a suspicion as to the correctness of the constant of the electro-dynamometer. In fact it appears from the figures given above that the dimensions of the

TABLE V.

E. M. F. of Cadmium Cells compared by means of the Electro-dynamometer.

Cell No.	Temperature of cell.	Temperature of Coil R.	Mass in grams.	Resistance R at $t°$ C.	$Rt \times \sqrt{m}$
	T	t	m	Rt	(No. 5) × (4)½
No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.
Cadmium 7	20.60	22.70	23.0977	.996850	4.79087
" 8	"	22.50	23.1074	.996793	4.79160
" 9	"	22.40	23.1359	.996769	4.79444
" 10	"	"	23.1197	.996769	4.79275
" 11	"	"	23.1123	.996769	4.79199
" 12	20.66	"	23.1096	.996769	4.79172
" 13	20.70	"	23.1011	.996769	4.79083
" 14	20.78	"	23.1027	.996769	4.79100
" 15	20.80	"	23.1359	.996769	4.79443
" 7	22.50	23.50	23.1254	.997029	4.79460
" 8	22.52	"	23.1181	.997029	4.79384
" 9	22.58	"	23.1234	.990729	4.79439
" 10	22.59	"	23.1367	.997029	4.79577
" 13	22.60	"	23.1180	.997029	4.79384
" 16	22.44	"	23.1138	.997029	4.79340
" 17	22.44	"	23.1118	.997029	4.79319
" 18	22.40	"	23.1177	.997029	4.79381
" 19	22.40	"	23.1187	.997029	4.79391
" 12	21.80	22.50	23.1120	.9967924	4.79208
" 12	21.80	"	23.1152	.9967924	4.78241
" 13	22.42	23.50	23.1185	.9970289	4.79388
" 13	22.42	"	23.1146	.9970289	4.79348
" 16	22.70	23.70	23.1133	.9970756	4.79357
" 16	22.70	"	23.1170	.9970756	4.79395
Mean	21.70				4.79316

cross-sections of the coils are too great in proportion to the size of the apparatus, so that it is probable that the series converges so slowly that more terms should have been used in the calculation, although this is already extremely laborious. While therefore no stress is laid on these as absolute measurements, there is no reason to doubt the correctness of the relative values. We accordingly obtain for the ratio,

$$\frac{\text{Clark at } 15°}{\text{Cadmium at } 21.7°} = \frac{6.74744}{4.79316} = 1.4077.$$

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" 13	22.60	"	23.1180	.997029	4.79384
" 16	22.44	"	23.1138	.997029	4.79340
" 17	22.44	"	23.1118	.997029	4.79319
" 18	22.40	"	23.1177	.997029	4.79381
" 19	22.40	"	23.1187	.997029	4.79391
" 12	21.80	22.50	23.1120	.9967924	4.79208
" 12	21.80	"	23.1152	.9967924	4.78241
" 13	22.42	23.50	23.1185	.9970289	4.79388
" 13	22.42	"	23.1146	.9970289	4.79348
" 16	22.70	23.70	23.1133	.9970756	4.79357
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Mean	21.70				4.79316

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$$\frac{\text{Clark at } 15°}{\text{Cadmium at } 21.7°} = \frac{6.74744}{4.79316} = 1.4077.$$

Jaeger and Wachsmuth,[1] working at the Reichsanstalt, find

$$\frac{\text{Clark at } 15^\circ}{\text{Cadmium at } 20^\circ} = 1.4063.$$

If we use the value 1.433 assumed by them for the Clark at 15°, our value would give for the Cadmium at 21.7 the value *1.0180 volts*, but it is worth noting that the determinations of the Clark cell at 15° now stand: Rayleigh, 1885, 1.4345; Carhart, 1.434; Glazebrook and Skinner, 1892, 1.4342; Kahle,[2] 1896, 1.4322.

In conclusion it may be stated that the writer has found no more difficulty in constructing cadmium cells than Clark. Furthermore the potentiometer measurements given in Table I show that it is possible to construct cadmium cells which shall be as uniform in E. M. F. as the best Clark elements. More time, however, will be required to determine how well these cells maintain their E. M. F., but at the last measurement there was no sign of increasing variation.

It remains for me to express my thanks to Professor A. G. Webster for his continual advice and assistance during the prosecution of this work, and to the authorities of Clark University for providing the necessary apparatus.[3]

[1] Jaeger u. Wachsmuth, Das Cadmium-Normalelement, Wied. Ann., 39, p. 575, 1896.

[2] Kahle, Das Helmholtz'sche absolute Electro dynamometer, Wied. Ann., 59, p. 532, 1896.

[3] Since the above was handed in, an article has appeared in the Zeitschrift für Instrumentenkunde, June, 1898, by Jaeger and Kahle, giving as the final results for the above ratio,

March, 1896,	1.4066
January, 1897,	1.40676
November, 1897,	1.40660
Mean,	1.40663

and in September, an article by Kahle, giving the ratio as obtained from absolute determinations, as 1.40703.

ON THE OSMOTIC PRESSURE OF CERTAIN ETHER SOLUTIONS AND ITS RELATION TO BOYLE-VAN'T HOFF'S LAW.

By H. M. Goodwin and George K. Burgess.

In a recent article on "The Determination of Osmotic Pressure by Means of Vapor Pressure Measurements"[1] Noyes and Abbot have shown how the osmotic pressure of a solution may be calculated from the specific gravity of the solvent, the relation of its molecular volume in the vapor state to pressure, and the vapor pressure of the solution. A method was worked out for determining the last of these quantities and measurements were made on solutions of naphthalene and of azobenzene in ether, from which the osmotic pressure was computed and the validity of the Boyle-Van't Hoff law tested for solutions varying in concentration from about one per cent. to twenty-five per cent. Ether was used as solvent at 12.90° C. and under reduced pressure, 330.48 mm., in order that the data of Ramsay and Young on the specific volume of its unsaturated vapor might be available in the computation.

The main results of the experimental part of this investigation are shown in the following abbreviated table, in which P is the osmotic pressure of the solution in kilograms per square centimeter and C the concentration expressed as mols per liter of solution.

Naphthalene.			Azobenzene.		
P	C	$\frac{P}{C}$	P	C	$\frac{P}{C}$
1.562	0.0559	27.93	0.958	0.0393	24.35
6.875	0.2727	25.21	4.620	0.1922	24.04
12.87	0.5286	24.35	8.858	0.3733	23.73
23.79	0.9978	23.84	16.71	0.7055	23.66
27.80	1.172	23.73	19.62	0.8289	23.67

[1] Zeit. für Phys. Chem., 23, 56, 1897.

The theoretical value of P/C or PV (V being the volume occupied by one molecular weight) for hydrogen gas at 12.90° and expressed in the same units (kilogram, liters) is 24.27, from which it is seen by inspection of the columns containingt he values of P/C, that in the case of azobenzene the proportionality between osmotic pressure and concentration, even to great concentrations, is very striking. In the case of naphthalene the proportionality is not so exact, the value P/C or PV diminishing some 16% with increasing concentration, or, in other words, deviating from Boyle's law in the same direction as the more compressible gases.

Although the estimated error in the case of the dilutest solutions was about 4%, the authors did not lay much weight on the results for these solutions, and were inclined to attribute the anomalous behavior of naphthalene to experimental error rather than to a real deviation from the gas law, especially as it was for dilute solutions of all others that one would naturally expect the relation to hold most exactly.

It was to further test this relation that we undertook the following work, the authors of the mentioned paper being obliged to discontinue further work along this line. Although practically the same experimental method has been employed, it was found necessary to rebuild the greater part of the apparatus, so that the following results can be regarded as entirely independent of the preceding as far as possible instrumental errors are concerned.

PRINCIPLE OF METHOD.

For convenience a brief recapitulation of the method may not be out of place here.

The osmotic pressure P of a solution is easily shown to be given by the integral[1]

$$P = \frac{s_0}{M}\int_p^{p_0} v\,dp \qquad (1)$$

where s_0 is the specific gravity and M the molecular weight of the solvent, v the molecular volume of the vapor, p_0 the vapor pressure

[1] Here the compressibility of the solvent, and the diminution in vapor pressure of the solution, compared with the total osmotic pressure, are assumed negligible.

of the solvent, and p that of the solution. In order to integrate this equation it is necessary to express v as a function of p. Unfortunately, exact data for this purpose are very meager (unless the gas laws be assumed), that furnished by the investigations of Ramsay and Young being the most reliable. Hence the choice of solvents was restricted to those for which an empirical relation between the specific volume of unsaturated vapor and the pressure had been established. We chose ether at 12.90° and 330.48 mm. pressure under which conditions Ramsay and Young worked,[1] for the same reasons as did Noyes and Abbot. We had hoped to extend the experiments also to 50°, but the difficulties involved in working with the apparatus at pressures greater than an atmosphere have prevented our doing so thus far.

The relative density δ of ether vapor referred to hydrogen at 12.90° is given by the equation[2]

$$\delta = 36.08 + 0.0581\, p,$$

where p is the pressure in centimeters. Hence

$$v = \frac{M}{wp\delta} = \frac{M}{wp(a + bp)}$$

where w is the weight of one cubic centimeter of hydrogen at 12.9° C. and 1 cm. pressure, and a and b the numerical constants in the above equation for δ.

Integrating (1) by means of this relation we obtain

$$P = \frac{s_0}{aw} ln \frac{p_0(a + bp)}{p(a + bp_0)} \qquad (2)$$

from which P can be computed when p_0, p and s_0 are known. In order to obtain from the percentage composition by weight of the solution the volume occupied by one molecular weight of the dissolved substance, it is necessary to know in addition the specific gravity of the solution.

[1] Philosophical Transactions, 178, 63.

[2] Noyes and Abbot, Zeit. für Phys. Chem., 23, 72, 1897.

APPARATUS.

The method employed for measuring the vapor pressure was a dynamical one, first suggested by Raoult,[1] but apparently discarded by him as being less convenient than the statical method. It consists in causing the solution to boil at the same temperature as the pure solvent, the external pressure being adjusted until this is effected. The diminution of pressure necessary to effect this is the desired lowering of the vapor pressure of the solution. For details of the apparatus and method reference must be made to the paper of Noyes and Abbot. For convenience and clearness the main features only will be mentioned here. The temperature of the boiling solution was indicated by means of a platinum resistance thermometer of about 100 ohms resistance, which forced one arm of a Wheatstone bridge. The three other arms of the bridge consisted of coils of manganine wire of about 100 ohms resistance, maintained at a constant temperature in a thermostat. A sensitive reflecting galvanometer was employed for indicating a balance in the bridge. It was capable of indicating with certainty a change in temperature of 0.001° of the platinum thermometer, this temperature variation producing a deflection of 1.8 mm. on the scale. Thermoelectric disturbances were compensated by means of an adjustable counter electromotive force in the galvanometer circuit. The pressures were read by means of a cathetometer, reading to 0.02 mm., on a mercury cistern manometer connected with the boiling flask through five large air reservoirs of equal capacity, which were maintained at constant temperature in the above-mentioned thermostat. The manometer was calibrated against a standard barometer. The boiling flask proper, of about 200 cc., was completely jacketed by an outer boiler in which pure ether was caused to boil at a pressure a few millimeters in excess of that in the boiling flask itself, thus maintaining the temperature of the surroundings within a fraction of a degree of that of the boiling solution.

The whole bridge arrangement was adjusted once for all by placing the platinum resistance thermometer and a primary standard mercury thermometer (calibrated at the Reichsanstalt), reading

[1] Ann. de Chim. et Phys., 20, 315, 1890.

by estimation to 0.005°, side by side in an ether bath brought to exactly 12.90°, while the manganine coils in the thermostat were kept at the temperature at which they were subsequently maintained during a run. The conditions during this fundamental adjustment were brought as near as possible to those under which the actual measurements were made. This adjustment was made by Noyes and Abbot by bringing the pressure in the boiling flask to exactly Ramsay and Young's value 330.48 mm., causing the ether to boil with the resistance thermometer in place, and adjusting the bridge until no deflection was produced by the galvanometer. It seemed to us, however, more desirable to adjust the bridge with the ether and coil at the proper *temperature*, than under the conditions of the corresponding pressure.

The procedure in each experiment was as follows: 125 cc. of ether was introduced into the flask by means of a calibrated pipette, and the pressure adjusted by means of a suction pump and conveniently arranged stopcocks until, when the liquid was boiling briskly, no deflection was produced on closing the galvanometer circuit. This gave the vapor pressure p_0 of the solvent when boiling at 12.90° C. Weighed portions of the substance in the form of short sticks were then introduced into the ether without opening the apparatus, by the device employed by Abbot. The pressure was then readjusted until again no deflection of the galvanometer was produced, that is, until the solution boiled constantly at the original temperature of the boiling solvent. The mean of at least four independent adjustments of the pressure was taken in each case. The average deviation of the mean was about 0.02 mm. The observed difference of pressure $p_0 - p$, corrected for temperature and for the variation of level of mercury in the manometer cistern gave the vapor pressure lowering of the solution. The time required to carry through a run at ten different concentrations was from eight to ten hours.

Specific Gravity Measurements.

Duplicate measurements in each case, which checked to 0.1%, were made as follows: about 75 cc. of ether was weighed in a 100 cc. flask with tight fitting stopper, to which a weighed portion

of the solute was added. The flask was then connected with a drying tube and with a Sprengel-Ostwald pyknometer of 20 cc. capacity, which was immersed in water at 0.0° C. This was filled by forcing the solution into it by blowing through the drying tube. It was then transferred to a bath at 12.90° C. and the solution brought to the reference mark. To prevent loss of ether due to expansion and evaporation, the ends of the pyknometer were closed with spherical bulbs, one of which was sealed and the other drawn out to a capillary. Weighings were made as quickly as possible.

PREPARATION OF ETHER.

About eight liters of sodium distilled ethyl ether of Kahlbaum's preparation were obtained, and to further purify the product, it was treated as follows: alcohols which may have been present were removed by treating fourteen times with a pure potassium hydrate solution (1 to 20,) in portions of about 300 cc. each. The final absence of color in the hydrate which settled out indicated complete removal of any alcohols. In a similar manner the ether was then washed five times with 100 cc. portions of water. 500 grams of calcium chloride were added and the mixture allowed to stand three weeks, with frequent agitation, after which the ether was distilled, the first and last portions of 100 cc. being discarded. The total time of distillation was twelve hours, divided among three successive days. The temperature on each day was constant to 0.1° C. and was 34.3° C. at 753 mm., 34.6° at 766 mm. and 34.3° at 752 mm. The distillate thus obtained showed practically no effervescence with metallic sodium.

The specific gravity of this ether at 12.90° was found to be 0.7210 (Noyes and Abbot, 0.7206; Kopp, 0.721), while its vapor pressure was 33.184 cm. Hg. (Ramsay and Young, 33.048 cm.; Noyes and Abbot, 32.990 cm.).

PREPARATION OF SUBSTANCES USED IN SOLUTION.

The substances used in solution were naphthalene, benzophenone and diphenylamine. The last two were chosen on account of their ready solubility in ether and their very high boiling point, both being over 300°. This is a very essential point, as the vapor pres-

sure of the dissolved substance is assumed in the calculation to be negligible compared with that of the solvent. All preparations were from Kahlbaum, and their purity was tested by determining the constancy of their freezing points. About 25 cc. of each substance was put into a test tube and heated in a sulphuric acid bath until completely liquified. It was then allowed to cool very slowly with constant stirring and the temperature noted until the whole mass had solidified. The freezing points were in each case practically constant so long as any liquid remained, and the substances were therefore considered sufficiently pure. The freezing points were: diphenylamine $53.61° \pm 0.04$; benzophenone $48.35° \pm 0.02$.

The naphthalene used was a portion of the same product used by Noyes and Abbot. It solidified at a constant temperature of 79.60°.

Experimental Results.

In Table I. are given the results of the specific gravity measurements. The first column contains the concentrations K (ratio of total weight of substance to weight of solvent) and the second the specific gravity at 12.90° C. referred to water at 4° C. A plot was made with these values for each substance, from which the specific gravity at any desired concentration was interpolated. The specific gravities used for the naphthalene solutions were those obtained by Noyes and Abbot.

Table I.

Naphthalene (Noyes and Abbot).		Benzophenone.		Diphenylamine.	
Concentration K.	Specific Gravity.	Concentration K.	Specific Gravity.	Concentration K.	Specific Gravity.
0.0514	0.7336	0.0041	0.7212	0.0153	0.7251
0.0674	0.7375	0.0214	0.7264	0.0478	0.7357
0.0800	0.7418	0.0465	0.7339	0.0708	0.7417
0.1392	0.7539	0.0816	0.7437	0.1158	0.7534
0.1406	0.7536	0.1062	0.7505	0.1243	0.7544
0.1761	0.7617	0.1169	0.7532	0.2217	0.7792
0.2243	0.7700	0.1234	0.7554		
0.2432	0.7764	0.1852	0.7705		
0.2589	0.7766	0.2770	0.7902		
0.2699	0.7796	0.4130	0.8165		

TABLE II.

NAPHTHALENE.

FIRST SERIES.

Weight of Ether = 89.01 *grams.*

Portion Number.	Weight of each Portion in grams.	Concentration.	p_0-p uncorrected.	p_0-p corrected.	Deviation of (p_0-p) from curve.
1	0.595	0.006685	0.181	0.188	+0.027
2	0.731	0.01490	0.371	0.385	+0.042
3	0.591	0.02154	0.513	0.532	+0.051
4	2.036	0.04441	0.862	0.894	−0.058
5	1.931	0.06610	1.261	1.308	rejected
6	2.690	0.09632	1.790	1.856	+0.014
7	4.356	0.1453	2.389	2.478	−0.110
8	4.128	0.1916	3.097	3.211	−0.036

SECOND SERIES.

Weight of Ether = 89.17 *grams.*

1	0.698	0.00783	0.182	0.189	+0.005
2	0.641	0.01502	0.292	0.303	−0.039
3	0.978	0.02598	0.506	0.525	−0.029
4	1.436	0.04209	0.816	0.846	−0.035
5	2.685	0.07221	1.324	1.373	−0.054
6	3.079	0.1067	1.921	1.992	−0.015
7	3.979	0.1514	2.598	2.694	+0.010
8	3.832	0.1944	3.182	3.299	+0.014
9	3.954	0.2387	3.794	3.935	+0.020

THIRD SERIES.

Weight of Ether = 88.85 *grams.*

1	0.406	0.00457	0.103	0.107	−0.003
2	0.379	0.00883	0.184	0.190	−0.021
3	0.580	0.01536	0.333	0.345	−0.005
4	0.463	0.02057	0.506	0.525	rejected
5	0.707	0.02853	0.605	0.627	+0.006
6	0.976	0.03953	0.833	0.864	+0.030
7	1.523	0.05666	1.123	1.164	+0.012

FOURTH SERIES.

Weight of Ether = 88.88 *grams.*

-	0.991	0.01115	0.242	0.251	−0.006
2	1.027	0.02271	0.498	0.516	+0.020
3	0.830	0.03204	0.685	0.710	+0.017
4	2.257	0.05744	1.143	1.186	+0.021
5	1.175	0.07066	1.353	1.403	+0.002
6	3.071	0.1052	1.923	1.995	+0.010

TABLE III.

BENZOPHENONE.

FIRST SERIES.

Weight of Ether = 89.02 *grams.*

Portion.	Weight in grams.	Concentration.	p_0-p observed.	p_0-p corrected.	Deviation of p_0-p from curve.
1	1.768	0.01986	0.259	0.269	+0.013
2	2.158	0.04410	0.554	0.575	+0.022
3	2.271	0.06961	0.857	0.889	+0.030
4	3.424	0.1081	1.267	1.314	+0.038
5	2.495	0.1361	1.561	1.619	+0.015
6	3.558	0.1760	1.928	1.999	+0.020
7	4.709	0.2290	2.380	2.468	−0.001

SECOND SERIES.

Weight of Ether = 89.04 *grams.*

1	1.058	0.01190	0.148	0.154	+0.012
2	1.728	0.03129	0.418	0.433	+0.003
3	2.400	0.05824	0.757	0.785	0.000
4	3.757	0.1004	1.219	1.270	+0.008
5	4.441	0.1503	1.739	1.803	−0.020
6	4.816	0.2044	2.163	2.243	+0.020
7	5.434	0.2654	2.655	2.753	0.000

THIRD SSRIES.

Weight of Ether = 88.86 *grams.*

1	1.025	0.01153	0.174	0.180	−0.014
2	1.435	0.02769	0.401	0.416	−0.001
3	1.201	0.04121	0.579	0.600	−0.028
4	1.546	0.05860	0.774	0.803	−0.010
5	2.934	0.09162	1.175	1.219	−0.033
6	2.775	0.1228	1.456	1.510	+0.020
7	4.016	0.1680	1.899	1.969	−0.022
8	4.149	0.2147	2.292	2.377	−0.030

Tables II., III. and IV. contain the observed data on the lowering of the vapor pressure of the solutions and their corresponding concentrations. The first column contains the number of each portion of the dissolved substance; the second, its weight; the third, the concentration K of the solution; the fourth, the mean of the observed differences of the cathetometer readings in centimeters,

TABLE IV.

DIPHENYLAMINE.

FIRST SERIES.

Weight of Ether = 88.64 *grams.*

Portion.	Weight in grams.	Concentration	p_0-p observed.	p_0-p corrected.	Deviation of p_0-p from curve.
1	1.303	0.01469	0.224	0.232	+0.025
2	0.909	0.02496	0.398	0.413	+0.015
3	1.259	0.03917	0.626	0.649	−0.002
4	1.861	0.06016	0.905	0.938	+0.018
5	2.228	0.08529	1.266	1.310	0.000
6	3.144	0.1208	1.727	1.791	0.000
7	3.887	0.1646	2.287	2.372	−0.020

SECOND SERIES.

Weight of Ether = 87.64 *grams.*

1	0.611	0.006971	0.146	0.152	−0.022
2	1.021	0.01862	0.316	0.328	−0.001
3	1.701	0.03803	0.610	0.633	−0.002
4	1.692	0.05733	0.877	0.910	+0.001
5	2.617	0.08720	1.292	1.340	−0.001
6	3.533	0.1276	1.801	1.872	+0.001
7	4.141	0.1748	2.361	2.448	+0.022

and the fifth, the corrected value obtained by multiplying by 1.037, the correction factor for the change of level of the mercury in the cistern of the manometer, and reduction to zero degrees.

The data for each solution was plotted on a large scale with values of $p_0 - p$ as ordinates and K as abscissæ and the best representative curve drawn through the points. From this curve of vapor pressure lowering, the value of $p_0 - p$ for even concentrations was interpolated. In the case of naphthalene and benzophenone, a residual plot was made on a large scale to ensure no sacrifice o precision of the data. This was obtained by assuming the equation of a straight line approximately representing the data, *i. e.*, $(p_0 - p) = \text{const.} \times K$, and finding the difference between the observed values of $p_0 - p$ and those computed from this equation for given values of the concentration. The best smooth curve representing these differences was then drawn, from which the values of $p_0 - p$ obtained from the assumed straight line could be corrected by the

proper amount. It was found that the mean values for the vapor pressure lowering obtained by this method were practically the same as those obtained from a large direct plot, so that in the case of diphenylamine only the latter was used.

In the last column of the above table is given the actual deviation of each observation from the curve taken as best representing all the data for each solution. The average of these deviations for the three solutions investigated is 0.025 cm. for naphthalene, 0.016 cm. for benzophenone, and .010 cm. for diphenylamine. For some unexplained reason the naphthalene solutions gave repeatedly the least concordant results. A treatment of Noyes and Abbot's data in the same manner as the above gives for the average deviation of all observations on naphthalene (four series), 0.024 cm., and for azobenzene (three series) 0.019 cm. Whether the irregularities presented by solutions of the former substance are due to its greater volatility, we have not been able to determine. The series cannot be regarded as satisfactory for solutions less concentrated than 5 per cent. in which case the error in the vapor pressure lowering is about two per cent. For a 10 per cent. solution the error in $p_0 - p$ is, however, only a little over one per cent. On the other hand, the agreement of the benzophenone and diphenylamine series is seen to be very much more satisfactory.

It should be mentioned that in order to eliminate constant errors as far as possible, the runs on each substance were not made consecutively; the separate runs with benzophenone, for example, were made two weeks apart, with several runs on naphthalene and diphenylamine made in the meantime. The good concordance of results on two of our solutions measured in this manner indicates that the apparatus was at all times in proper adjustment, and that the larger deviations observed with the naphthalene are probably due to variable causes inherent in the solution itself.

In Table V. are given the values of the vapor pressures of the solutions at even concentrations, expressed in centimeters of mercury at 0° C. These values are obtained by subtracting the lowering $p_0 - p$, obtained graphically as described above, from 33.184 cm., the mean value of a series of measurements of the vapor pressure of the pure ether used. This value differs by about 0.4

per cent. from that given by Ramsay and Young, namely, 33.048. We have thought best to use the observed value of p_0 in the computation rather than Ramsay and Young's, as it represents the true value of the pressure under the conditions of temperature at which the bridge adjustment was made. From the data in this table the value of the osmotic pressure was computed by formula (2), which reduces for computation to

TABLE V.

Concentration.	Naphthalene.		Benzophenone.		Diphenylamine.	
	Vapor Pressure.	Specific Gravity.	Vapor Pressure.	Specific Gravity.	Vapor Pressure.	Specific Gravity.
0.00	33.184	0.7210	33.184	0.7210	33.184	0.7210
.01	32.958	.7232	33.039	.7236	33.005	.7238
.02	32.736	.7258	32.899	.7264	32.840	.7269
.03	32.534	.7283	32.763	.7291	32.679	.7300
.05	32.153	.7330	32.502	.7351	32.377	.7357
.07	31.798	.7376	32.254	.7420	32.092	.7407
.10	31.287	.7443	31.911	.7492	31.676	.7494
.13	30.817	.7512	31.604	.7569	31.275	.7561
.16	30.376	.7578	31.312	.7645	30.888	.7645
.20	29.822	.7663	30.958	.7741		
.24			30.552	.7851		

$$P = 554300 \left[\log_{10} \frac{a + bp}{p} + \bar{1}.94103 \right]$$

by introduction of the numerical value of the constants $a = 36.08$; $b = 0.0581$; $p_0 = 33.184$; $s_0 = 0.7210$; $w = \frac{0.08987 \times 273.1}{286.0 \times 76}$ and the factors 13.60, the specific gravity of mercury to reduce the pressure to grams, and 2.303, to convert Naperian to Briggs' logarithms.

In Table VI., column five, is given the result of this computation, at concentrations expressed in the following units:

K, as previously defined, the fractional concentration by weight.

C_1 the number of gram molecules of solute in one kilogram of solvent (Raoult);

C_2 the number of gram molecules of solute in one liter of solution (Arrhenius);

TABLE VI.

NAPHTHALENE.

K	C_1	C_2	C_3	P	$P:C_1$	$P:C_2$	$P:C_3$	$100\frac{\Delta P}{P}$
0.01	0.0781	0.0559	0.00575	1.577	20.36	28.19	276.6	10.
.02	0.1563	.1112	.01143	3.080	19.72	27.69	269.5	5.2
.03	0.2344	.1657	.01706	4.507	19.23	27.20	264.2	3.6
.05	0.3906	.2727	.02810	7.200	18.45	26.41	256.5	2.3
.07	0.5468	.3769	.03889	9.745	17.82	25.86	250.6	1.8
.10	0.7812	.5286	.05465	13.39	17.14	25.34	246.6	1.4
.13	1.015	.6752	.06985	16.93	16.68	25.08	242.4	1.2
.16	1.250	.8166	.08468	20.24	16.19	24.79	239.0	1.1
.20	1.563	.9978	.10370	24.45	15.65	24.51	235.8	0.98

BENZOPHENONE.

0.01	0.0550	0.0394	0.00405	0.987	17.96	25.07	243.6	11.
.02	0.1100	.0783	.00807	1.957	17.81	25.01	242.6	5.7
.03	0.1648	.1167	.01206	2.904	17.62	24.90	240.9	3.9
.05	0.2747	.1924	.01994	4.734	17.23	24.62	237.5	2.5
.07	0.3846	.2667	.02767	6.493	16.88	24.34	234.5	1.9
.10	0.5495	.3743	.03904	8.939	16.26	23.88	228.9	1.4
.13	0.7143	.4783	.05023	11.15	15.62	23.33	222.1	1.2
.16	0.8791	.5792	.06110	13.28	15.11	22.93	217.4	1.1
.20	1.100	.7089	.07521	15.90	14.47	22.43	211.4	1.0
.25	1.374	.8630	.09232	18.91	13.77	21.92	204.9	0.93

DIPHENYLAMINE.

0.01	0.0593	0.0422	0.00446	1.220	21.95	28.76	279.7	5.6
.02	.1184	.0843	.00868	2.373	20.05	28.12	273.2	3.1
.03	.1775	.1259	.01297	3.492	19.67	27.76	269.4	2.1
.05	.2959	.2073	.02142	5.620	19.00	27.11	262.4	1.4
.07	.4142	.2866	.02977	7.645	18.46	26.68	257.0	1.2
.10	.5925	.4031	.04197	10.635	17.97	26.38	253.4	0.97
.13	.7692	.5148	.05388	13.54	17.60	26.31	251.4	0.88
.16	.9467	.6242	.06546	16.39	17.33	26.28	250.5	0.83

C_3 the number of mols of solute dissolved in one mean gram molecular weight of the solution (Planck).

The last three columns contain the ratio of osmotic pressure to concentration, or what is the same, the product of osmotic pressure and corresponding volume expressed in units defined above. The last column contains the value of the percentage error in P. If in

(2) we put $p_0 - p = \triangle p$; $d_0 = a + bp_0$; and $\frac{s_0}{w} = \text{const.}$, we obtain by a simple transformation and expansion by Maclaurin's theorem $P = \text{const.} \times \frac{1}{d_0} \times \frac{\triangle p}{p_0}$ approximately, in which d_0, p_0 and $\triangle p$ are the variables to be considered in computing the accuracy of P. Hence the fractional error in P is

$$\frac{\triangle P}{P} = \sqrt{\left(\frac{\delta d_0}{d_0}\right)^2 + \left(\frac{\delta \triangle p}{\triangle p}\right)^2 + \left(\frac{\delta p_0}{p_0}\right)^2}.$$

The assumption is here made that the error in s_0 is less than 0.1% and negligible together with the error in w. In computing $\frac{\triangle P}{P}$ the values taken for $\delta(\triangle p)$ are those on pages 178–180; $\frac{\delta d_0}{d_0}$ and $\frac{\delta p_0}{p_0}$ are each taken equal to 0.005, these values being considered the most probable ones assignable.

It is evident from an inspection of Table VI. that strict proportionality between osmotic pressure and concentration does not hold,

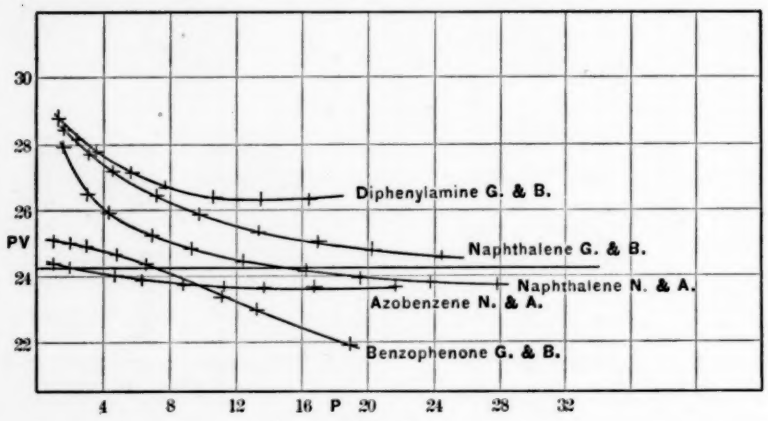

Fig. 1.

however the concentration be computed. The ratio diminishes in all cases and by different amounts for the different substances. Furthermore, the values of $P \div C_2$ or PV, where V is the volume occupied by one mol, are not equal for the same cencentrations of

the different solutions as they should be if each dissolved substance followed the laws of a perfect gas. These relations are more clearly seen by reference to the plot, in which values of $P \div C_2 = PV$ are plotted as ordinates and P as abscissæ, not only for our solutions but also for those investigated by Noyes and Abbot. The heavy horizontal line at 24.27 represents the corresponding curve for hydrogen gas at the same temperature, 12.90°C.

Although but little weight can be given to the numerical value of the measurements on the dilute solutions on account of the large experimental error, yet inspection of the curves indicates that none of the substances investigated follows strictly the laws of a perfect gas. Azobenzene approaches very nearly to the ideal condition as already pointed out by Noyes and Abbot. The curves for the other three substances, on the other hand, resemble very markedly those of imperfect gases under pressures at which the effect of molecular attraction preponderates over that of covolume. Thus the decrease in the value of PV for benzophenone is very marked and the curve shows no indication of reaching a minimum even at 20 atmospheres.

The naphthalene curve obtained by us is of practically the same form as that obtained by Noyes and Abbot, but uniformly higher. The cause of this constant discrepancy is not clear; we have been unable to discover any source of constant error in our measurements of this amount. It may be due, in part at least, to the different preparation of ether used, and to the method of making the fundamental adjustment of the apparatus, page 174. The form of the curve, however, is in very satisfactory agreement with the earlier measurements.

Diphenylamine is particularly interesting, as the value of PV, after decreasing rapidly at first, apparently reaches a nearly constant value at about eighteen atmospheres, after which it probably increases,[1] exactly as is the case with imperfect gases under high pressures. The comportment of substances in solution and of imperfect gases would seem to be, from these results, completely analogous in their isothermal relation of pressure and volume. Whereas the general applicability of the $PV = RT$ relation to sub-

[1] An extrapolation of the vapor pressure curve indicates that this would be the case.

stances in dilute solution has been demonstrated in numerous recent investigations, yet our experiments seem to indicate that this equation is more or less deviated from by different individual solutes, in much the same way as the relation is departed from by imperfect gases, such as nitrous oxide, ammonia, etc., at not too high temperatures and at great pressures.

The fact that in all of the solutions investigated the greatest variations of PV are in the dilutest solutions, whereas, on theoretical grounds, the contrary is to be expected, appears to us to warrant no final conclusions at present in view of the unavoidable large error in measurements of the lowering of the vapor pressure of such dilutions. We hope to be able soon to greatly increase the accuracy of vapor pressure measurements of dilute solution, by a new method, the preliminary results of which give much promise of success.

The fact that the values of PV for the dilute solutions are in all cases greater than 24.27, the value for hydrogen, is also deserving of notice. This might be explained by a dissociation of the dissolved substances in the dilute solutions. Such an assumpton, however, without at least further confirmation, seems, in view of the nature of the solvent and solutes used, highly improbable.

CONCLUSION.

The osmotic pressure of solutions of naphthalene, benozphenone, and diphenylamine in ether at 12.90° C. was determined from measurements on the vapor pressure of these solutions at concentrations varying from about 0.01 to 1.0 normal corresponding to osmotic pressures from about one to twenty-five atmospheres. A study of the variation of the product PV with the pressure indicates that none of these substances in solution comports itself like a permanent or perfect gas, but rather like an imperfect or readily compressible gas, as the product unmistakably decreases with increasing pressure. This is very marked in the case of benzophenone and less so with naphthalene; in the case of diphenylamine the product diminishes up to about eighteen atmospheres, when it becomes constant or increases. Azobenzene, investigated by Noyes and Abbot

approaches, on the other hand, quite nearly to the condition of a perfect gas. It would seem therefore probable, that every substance when in solution has its own characteristic condition equation connecting temperature, osmotic pressure and volume, analogous to every more or less readily compressible gas, even when complications arising from dissociation or polymerization phenomena are, from the nature of the solvent and solute used, highly improbable. Substances analogous to the permanent gases would seem to be the exception rather than the rule.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY,
ROGERS LABORATORY OF PHYSICS, May, 1898.

NOTE.

The American Association for the Advancement of Science.—The jubilee meeting of the Association and celebration of the fiftieth anniversary of its foundation was held in Boston, August 22 to 27, 1898. This meeting, for which elaborate preparations had been made by the local committees and by the officers of the Association, was highly successful. The attendance was much larger than at any meeting of recent years. The programs of all the sections were unusually full and were of great interest. Through the hospitality of Boston, Cambridge and Salem, which was lavishly extended, the opportunities for social intercourse were more than ample. Indeed, if any criticism upon the management of the meeting were to be offered it would be that the amount of time set aside for the entertainment of the members too seriously curtailed the sittings of the various sections.

The result, so far as the work of Section B was concerned, was a congestion which became more and more acute from day to day, until in the closing hours papers of more than ordinary interest and importance were allotted a scant five minutes for presentation, or were in some cases read simply by title. Discussion during these closing sessions of the section was almost entirely suppressed, not by the action of the Chairman, but by the universal feeling that it was necessary to get through the program with the least possible delay.

The sixty papers upon the physics program, in addition to the address of the Chairman, Professor F. P. Whitman, could perhaps have been successfully handled in the course of the session at one of the ordinary meetings of the Association; but under the conditions which existed at the Boston meeting it was impossible to do justice to so long a list. What visiting physicists lost in this respect was, however, in great measure made up to them by unusual opportunities for meeting their fellow workers in the domain of physics. The sittings of the section were held in the Physical Lecture Room of the Massachusetts Institute of Technology and (on Friday) at the Jefferson Physical Laboratory of Harvard University.

The following is a list of the papers presented to the section.

The Measurement of Thermal Conductivity in Iron. By E. H. Hall.

On Energy and Entropy. By L. A. Bauer.

Second Report on the Magnetic Survey of Maryland. By L. A. Bauer.

On the Magnetic Deflection of Diffusely Reflected Cathode Rays. By Ernest Merritt.

On the Electrical Properties of the Vapors from the Arc. By Ernest Merritt and O. M. Stewart.

The Heat of Fusion of Ice Determined in Electrical Units. By E. L. Nichols.

The Hysteresis of Iron and Steel at Ordinary Temperatures and at the Temperature of Solid Carbon Dioxide. By A. M. Thiessen.

The Electrical Resistance of Lead Amalgams at Low Temperatures. By G. W. Gressman.

The Most Efficient Thickness of Transformer Plate. By F. Bedell, R. M. Klein, and T. P. Thompson.

The Resistance of Iron Wires for Alternating Currents of Ordinary Frequencies. By Ernest Merritt.

A Harmonic Piano and Organ. By Levi Orser.

A New Chronograph and a Means of Rating Tuning Forks. By A. G. Webster.

An Improved Method for Rating Tuning Forks. By J. O. Reed.

A Geometrical Method for Investigating Diffraction by a Circular Aperture. By A. G. Webster.

On the Efficiency of Condensers. By E. B. Rosa and A. W. Smith.

The Effect of Fibrous Structure in Iron on its Change of Length when Magnetized. By E. Rhoads.

Notes on the Effect of Silicon on the Magnetic Permeability of Iron. By F. C. Caldwell.

On the Measurement of Electrical Oscillations of Short Period and Their Absorption by Water. By A. D. Cole.

The Effect of the Secondary on the Period of Oscillation in a Primary Condenser Circuit. By J. H. Smith.

An Acoustical Micrometer. By J. O. Reed.

A Fuel Combustion Bomb. By C. L. Norton.

On the Use of Window Glass having a Diffusive Action on Light. By C. L. Norton.

A Devise for Recording Photometer Readings. By C. P. Matthews.

Polarization in the $Zn - H_2SO_4$ cell. By Professor W. A. Anthony.

On Certain Constants Relating to Arc Lighting. By William Harkness.

Report on the Recent Progress in the Dynamics of Solids and Fluids. By Ernest W. Brown.

Report on the Recent Progress in the Mathematical Theory of Electricity and Magnetism. By Arthur G. Webster.

The Mass and Moments of Inertia of the Earth's Atmosphere. By R. S. Woodward.

The New Forms of Apparatus for Measuring the Acceleration of Gravity. By R. S. Woodward.

The Gravitation Constant and the Mean Density of the Earth. By R. S. Woodward.

The Limitations of the Present Solution of the Tidal Problem. By John S. Hayford.

Photographic Studies of the Electric Arc. By N. H. Brown.

Exhibition of Certain Models in Physics and Dynamics. By Carl Barus.

The Structure of Cyclones and Anticyclones. By F. H. Bigelow.

Temperature and Vapor Gradients in the Atmosphere. By F. H. Bigelow.

Report on the Velocity of Light in a Magnetic Field. By Edward W. Morley, Henry T. Eddy and Dayton C. Miller.

A Study of Standard Meter Scales ruled on Nickel, Silver and Glass. By D. C. Miller.

An Apparatus for Demonstrating, in Alternating Currents, the Change of Phase due to either Inductance or Capacity. By Sidney T. Moreland.

An Apparatus for Determining Coefficients of Induction. By Sidney T. Moreland.

Study of Elastic Fatigue by the Time Variation of the Logarithmic Decrement. By J. O. Thompson.

A Redetermination of the Ampere. By Geo. W. Patterson and Karl E. Guthe.

Polarization and Internal Resistance of the Voltaic Cell. By Karl E. Guthe.

A New Gas. By Charles F. Brush.

Hysteresis Loss in Iron for very small Ranges of Induction. By Henry S. Webb.

Note on the Testing of Optical Glass. By W. S. Franklin.

A Lecture Room Experiment in Electrostatics. By W. S. Franklin.

A Study of Galvanic Polarization. By Barry McNutt.

On a Normal Curve of Magnetization of Iron. By S. S. Clark.

Some Determinations of Dielectric Strength. By Thomas Gray.

On the Efficiency of Condensers. By E. B. Rosa and A. W. Smith.

A Calorimetric Determination of the Energy Dissipated in Condensers. By E. B. Rosa and A. W. Smith.

Graphical Treatment of Mutually Inductive Circuits with Special Reference to the Case of Variable Frequency. By H. T. Eddy.

The Effect of Fibrous Structures in Iron or its Change of Length when Magnetized. By E. Rhoads.

Progress in the Exploration of the Air with Kites at the Blue Hill Observatory. By A. Lawrence Rotch.

An Instrument for Measuring Radiance. By Professor Knut Ångström, Upsala. Exhibited by E. S. Ferry.

Exhibit of an Automatic Mercurial Air Pump Designed by Professor E. W. Morley. By D. C. Miller.

On the Relative Brightness of Pigments by Oblique Vision. By F. P. Whitman.

On the Osmotic Pressure of Certain Ether Solutions and the Validity of the Boyle-Van't Hoff Law. By H. M. Goodwin and George K. Burgess.

On the Dielectric Constant and Electrical Conductivity of Liquid Ammonia. By H. M. Goodwin and Maurice DeKay Thompson, Jr.

A New Instrument for the Measurement of the Intensity of Sound. By A. G. Webster and Mr. B. F. Sharpe.

NEW BOOKS.

Magnetic Fields of Force. Part I. By H. EBERT. Translated by C. V. BURTON. Pp. vii + 297. London and New York, Longmans, Green & Company, 1897.

In this English edition the author has endeavored to make a faithful translation of the original, the changes he has introduced being few and distinguished by square brackets. The book is well gotten up and makes an interesting and attractive volume. The author lays especial stress on three fundamental conceptions: "the conception of lines of force, the conception of energy in a magnetic or electromagnetic field, and the symmetry of the medium which is the seat of the electromagnetic force." The book begins with methods for mapping diagrams of magnetic fields by means of iron filings and methods for fixing such diagrams, and these have been reproduced in almost too great profusion, accompanied by detailed discussion. The author thus aims to develop the fundamental conceptions of magnetic fields and lines of force by experiment rather than by means of artificial hypotheses. Many of these experiments may be readily performed in the laboratory, the directions for so doing being complete. About one-third of the book is thus devoted to a gradual introduction, qualitative in character, before the quantitative relations of Coulomb's law of attraction, unit pole, unit field, magnetic moment, etc., are discussed. Electromagnetism is discussed after magnetism; it is not until page 256 that the quantitative relation between magnetizing force and ampère turns is introduced. The dimensions of quantities employed in formulæ are commonly given; *e. g.*, $\mathfrak{h} = 4.2$ cm.$^{-\frac{1}{2}}$ gr.$^{\frac{1}{2}}$ sec.$^{-1}$.

The book forms a rather exhaustive discussion of magnetic fields of force from the physical standpoint, and as such, will be of interest to the physicist. It should be read consecutively, the discussions being too complete to make the book available for ready reference. The author states that this first part of the book is intended to serve rather the purpose of an introduction. "The second part will deal with the phenomena of induction, and, as before, qualitative relations will be dealt with apart from quantitative."

F. BEDELL.